SEVENTEENTH INTERNATIONAL CONFERENCE
MECHANICS OF COMPOSITE MATERIALS

May 28-June 1, 2012
Riga, Latvia

BOOK OF ABSTRACTS
Eds. V. Tamužs, K. Cīrule, and V. Kulakovs

Riga, 2012
ORGANIZING INSTITUTION

• Institute of Polymer Mechanics

SUPPORTING INSTITUTIONS

• Latvian Academy of Sciences
• Latvian Council of Science
• Latvian National Committee for Mechanics
• University of Latvia
• Riga Technical University
• Journal Mechanics of Composite Materials
• Centre Composite (Latvia)

SCIENTIFIC PROGRAMME COMMITTEE

Chairman: V. Tamužs (Latvia)

Vice-chairmen: E. Plūme (Latvia)
                 J. Jansons (Latvia)

Scientific Secretary: K. Cīrule (Latvia)

L. A. Agalovyan (Armenia), S. D. Akbarov (Turkey), H. Altenbach (Germany),
A. N. Anoshkin (Russia), C. Bakis (USA), W. Hwang (Republic of Korea), V. V. Kovriga
(Russia), A. Kvedaras (Lithuania), J. Lellep (Estonia), A. B. Mitkevich (Russia),
V. G. Piskunov (Ukraine), Yu. M. Pleskachevsky (Belarus), Yu. V. Sokolkin (Russia),
R. Talreja (USA), R. Tepfers (Sweden), J. Värna (Sweden), and A. D. Zamanov (Azerbaijan)

LOCAL ORGANIZING COMMITTEE

Chairman: E. Plūme

J. Andersons, K. Aniskevich, M. Auziņš, J. Brauns, A. Čate, K. Cīrule, T. Glaskova,
J. Jansons, M. Kalniņš, K. Klepatšky, I. Knēts, A. Krasņikovs, A. Lagziņš,
R. Maksimov, L. Pāže, K. Rocēns, V. Štrauss, J. Vība
FOREWORD

Since 1965, with intermissions of two to three years, Riga has been hosting regular conferences on the mechanics of polymer and composite materials organized by the Institute of Polymer Mechanics. The scope of problems covered at these conferences has always been wide, incorporating all the basic aspects of this field of science.

In the best traditions and spirit of the previous fifteen forums, the seventeenth Conference will be discussing a wide spectrum of topics related to the mechanics of composites, including nanocomposites, such as the structure and properties, long-term deformational properties and durability, strength, fracture and fatigue, composite structures, application of composite materials in aeronautics and space, technology (mechanical aspects), and composites in civil engineering and infrastructure.

The present Book of Abstracts comprises 218 abstracts of 477 contributors from 36 countries (Algeria, Azerbaijan, Belarus, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, France, Greece, Germany, Hungary, Iran, India, Israel, Italy, Jordan, Kazakhstan, Korea, Latvia, Lithuania, Luxembourg, Malaysia, Malta, Poland, Portugal, Romania, Russia, Saudi Arabia, Scotland, Spain, Sweden, Turkey, Ukraine, United Kingdom, U.S.A).

The full papers having passed the reviewing procedure and having met the demands of the periodical will be published in the journal Mekhanika Kompozitnykh Materialov/Mechanics of Composite Materials issued by the Institute of Polymer Mechanics.

The Organizing Committee expresses thanks to all the contributors of the abstracts and wishes the delegates fruitful participation in the Conference, as well as a pleasant stay in Riga and Jurmala.

Organizing Committee
CONTENTS

FOREWORD

CONTENTS

QUALITY ASSESSMENT OF A NUMBER OF SCREW-FIXED DAMAGES AT THE PARTICLE-BOARD SURFACE: VARIOUS SCREW TYPES IN THREE DIFFERENT SCREW INSERTION TECHNIQUES
F. Abu and M. Ahmad..........................................................20

ADSORPTION OF GLYCINE ONTO DLC AND F-DLC FILMS STUDIED BY XPS AND FTIR SPECTROSCOPY
M. Ahmed and J. A. Byrne.....................................................21

METHOD OF SOLUTION OF AXISYMMETRIC CONTACT PROBLEMS FOR COATINGS OF COMPLICATED STRUCTURE
S. Aizikovich, A. Vasiliev, and S. Volkov.................................22

TIME-HARMONIC LAMB’S PROBLEM FOR A SYSTEM CONSISTING OF AN IMPERFECTLY-CONTACTED ORTHOTROPIC COVERING LAYER AND AN ORTHOTROPIC HALF-PLANE
S. D. Akbarov and N. İlhan....................................................23

INFLUENCE OF THE INITIAL STRAINS OF FACE LAYERS ON THE TORSIONAL WAVE PROPAGATION IN A HOLLOW SANDWICH CYLINDER (SOFT CORE AND STIFF FACE LAYERS)
S. D. Akbarov, T. Kepceler, and M. M. Egilmez............................24

BUCKLING DELAMINATION OF ELASTIC AND VISCOELASTIC COMPOSITE PLATES WITH CRACKS
S. D. Akbarov........................................................................25

3D FEM ANALYSIS OF STRESS CONCENTRATIONS AROUND TWO NEIGHBORING CYLINDRICAL HOLES WITHIN A PRESTRESSED RECTANGULAR COMPOSITE PLATE UNDER BENDING
S. D. Akbarov, N. Yahnioglu, and U. Babuscu Yesil....................26

3D FEM ANALYSIS OF THE BUCKLING DELAMINATION OF A RECTANGULAR PLATE WITH AN INNER RECTANGULAR CRACK UNDER BIAXIAL COMPRESSIVE FORCE
S. D. Akbarov, N. Yahnioglu, and E. E. Karatas............................27

BUCKLING DELAMINATION OF A RECTANGULAR SANDWICH PLATE CONTAINING INNER CRACKS UNDER BI-AXIAL LOADING
S. D. Akbarov, N. Yahnioglu, and A. Tekin.................................28

CALCULATIONS OF FIBER-REINFORCED RIGID CYLINDERS UNDER THE INFLUENCE OF CENTRIFUGAL FORCES AND THE FRAME THEORY
V. M. Akhundov and T. A. Skripochka....................................29

INCREMENTAL FRAME THEORY OF FIBROUS MEDIA UNDER LARGE ELASTIC, CREEP AND PLASTIC DEFORMATIONS
V. M. Akhundov....................................................................30

METHOD OF FRAME BLOCKS IN THE MECHANICS OF COMPOSITE MATERIALS AT HIGH GRADIENTS OF STATE
V. M. Akhundov....................................................................31
ELASTIC AND DISSIPATIVE MATERIAL PROPERTIES OF ALUMINIUM ALLOYS WITH CARBON NANOTUBES
P. Akishin, E. Barkanov, R. Smyth, and T. McNally ............................................................ 32

NUMERICAL MODELLING OF HEAT DIFFUSION IN AN ORTHOTROPIC I-BEAM
P. Akishin, A. Aniskevich, and K. Aniskevich ................................................................. 33

ANALYSIS OF DELAMINATION IN LAMINATED COMPOSITE MATERIALS FOR HORIZONTAL-AXIS WIND TURBINE BLADE APPLICATION
O. Al-Khudairi, H. Hadavinia, B. Osborne and E. Lewis ................................................... 34

SOME EFFECTS OF VISCOELASTICITY ON THE ABILITY TO MODEL FAILURE IN COMPOSITES
D. H. Allen .......................................................................................................................... 35

DESIGN AND TESTING OF SANDWICH PANELS FOR TRAILERS
G. Allikas, A. Aruniit, H. Herranen, H. Lend, J. Majak, M. Pohlak, and O. Pabut ............. 36

ANALYTICAL MODEL TO PREDICT THE SHEAR CAPACITY OF REPAIRED DEFICIENT REINFORCED CONCRETE BEAMS DAMAGED BY SULFATE USING COMPOSITE MATERIALS
R. Alrousan and R. Haddad ................................................................................................. 37

ENVIRONMENT EFFECT ON THE PULSATING FLOW OF A LIQUID IN A MULTILAYER VISOELASTIC PIPE

A NOVEL ECOLOGICAL HEAT-INSULATING COMPOSITE OF A STEAM-EXPLODED BIOMASS
M. Andzs, J. Gravitis, and J. Abolins ................................................................................... 39

LINEAR VISOELASTIC APPROACH TO THE TENSILE CREEP OF EPOXY RESIN WITH A VARIABLE MOISTURE CONTENT
A. N. Aniskevich, R. M. Guedes, and O. Starkova ................................................................. 40

MECHANICAL PROPERTIES OF A LAYERED GLASS-FIBER-REINFORCED PLASTIC AFTER A FREEZE-THAW CYCLING
K. K. Aniskevich, V. P. Korkhov, and E. A. Faitelsone ......................................................... 41

MODELS AND METHODS FOR STRENGTH CALCULATION OF COMPOSITE MATERIALS AND CONSTRUCTIONS
A. N. Anoshkin ..................................................................................................................... 42

USE OF COMPOSITE MATERIALS IN AIRCRAFT POWER PLANTS CONSTRUCTION
A. N. Anoshkin and M. A. Grinev ......................................................................................... 43

PREDICTION OF THE EFFECTIVE ELASTIC PROPERTIES OF A SOUND-ABSORBING CIRCUIT’S FILLER OF AIRCRAFT ENGINES
A. N. Anoshkin, V. Yu. Zuyko, and E. N. Shustova ............................................................. 44

CHARACTERIZATION OF A COMBINED-CORE SANDWICH BEAM MADE FROM CORK AND POLYURETHANE
A. Arbaoui ........................................................................................................................... 45
STUDY ON THE MECHANICAL PROPERTIES OF SHELLAC FILMS Grafted WITH ACRYLIC MONOMERS 2-HYDROXYETHYL METHACRYLATE (HEMA) BY ULTRAVIOLET (UV)
A. Arnautov, V. Korhov, and E. Faitelson .................................................. 46

A WEDGE-TYPE ANCHORAGE SYSTEM FOR FRP COMPOSITE TENDONS

EFFECT OF LIGNINS ON THE STRUCTURE AND TENSILE AND THERMAL
PROPERTIES OF POLYURETHANES FILMS
A. Arshanitsa, L. Krumina, L. Vevere, and G. Telysheva .................................. 48

RELATION OF COMPOSITION AND PROCESSING PARAMETERS TO STAIN
RESISTANCE OF A PARTICLE-REINFORCED POLYMER COMPOSITE
A. Arunit, J. Kers, A. Krumme, R. Talalaev, H. Herranen, and O. Pabut ............... 49

COMPUTER SIMULATION OF THE DEFECTS IN
POLYTETRAFLUOROETHYLENE IRRADIATED BY IONS
K. N. Aryutkin, A. I. Kupchshin, B. A. Kozhamkulov, K. B. Tlebaev, and
T. A. Shmygaleva ................................................................................................. 50

ESTIMATION OF STRENGTH OF THE REINFORCED POLYETHYLENE PIPES
IN THE CONDITIONS OF LOW TEMPERATURES
F. I. Babenko, Y. Y. Fedorov, and A. K. Rodionov ............................................. 51

A STUDY ON THE MICROSTRUCTURES AND MECHANICAL PROPERTIES
OF AN IN-SITU LIQUID MIXING-PROCESSED FEAL/ZRC INTERMETALLIC
MATRIX COMPOSITE
K. C. Bae, J. M. Choi, I. M. Park, and Y. H. Park ................................................ 52

IMPACT BEHAVIOR OF MULTILAYERED B4C/AA7075 FUNCTIONALLY
GRADED MATERIALS AGAINST AN ARMOR-PIERCING PROJECTILE
E. Balci, B. Sarikan, M. Übeyli, and N. Camuşcu .............................................. 53

NONDESTRUCTIVE TECHNIQUES FOR A RELIABLE CHARACTERIZATION
OF ADVANCED COMPOSITE MATERIAL PROPERTIES
E. Barkanov, M. Wesolowski, P. Akishin, and S. Belouettar .................................. 54

INTERFACIAL PROPERTIES OF ALUMINUM/GLASS FIBER-REINFORCED
POLYPROPYLENE SANDWICH COMPOSITES
S. B. Baştürk, A. Guruşçu, and M. Tanoğlu ....................................................... 55

RESTORATION OF THE SPATIAL STRUCTURE OF HIGHLY-POROUS
POLYURETHANE FOAMS
I. Beverte and A. Zilaucs ...................................................................................... 56

USE OF GLASS FRP COMPOSITES FOR THE STRENGTHENING AND
STIFFENING OF SLENDER WEB PANELS OF STEEL I-BEAMS
M. A. Bhutto and I. M. May ................................................................................ 57

LOW-TEMPERATURE EFFECT ON THE MECHANICAL PROPERTIES OF
GLASS- AND CARBON-REINFORCED/EPOXY COMPOSITES AND FML
J. Bieniaś, B. Surowska, and K. Majerski ......................................................... 58

THE MECHANICAL PROPERTIES AND FAILURE ANALYSIS OF SELECTED
Fibre METAL LAMINATES
J. Bieniaś and B. Surowska .................................................................................. 59
IMPACT BEHAVIOUR OF FIBRE METAL LAMINATES
J. Bieniaś ........................................................................................................................................ 60

PHYSICOMECHANICAL PROPERTIES OF A POLYETHYLENE/CARBON
NANOTUBE COMPOSITE PREPARED USING A CONCENTRATE
OF NANOTUBES IN POLYETHYLENE
J. Bitenieks, R. Merijs Meri, J. Zicans, R. D. Maksimov, and E. Plume ........................................ 61

SOME PROPERTIES OF POLYOLEFINS TOUGHENED WITH ELASTOMERS
MODIFIED AND UNMODIFIED WITH A NANOFILLER
I. Bochkov, R. Merijs-Meri, T. Ivanova, J. Grabis, and R. Kotsilkova .............................................. 62

MECHANICAL PROPERTIES AND STRUCTURE OF A MWCNT/EPOXY RESIN
NANOCOMPOSITE
A. Borisova, T. Glaskova, K. Aniskevich, K. Kundzins, and E. Faitelson ........................................ 63

TIME EFFECT ON HSC WITH AND WITHOUT ADDITION OF FIBERS
O. Cazan and C. Măgureanu .................................................................................................................. 64

HEAT TRANSFER ENHANCEMENT OF COMPOSITE METAL HEAT-
EXCHANGING SURFACES
R. Chatys and Ł. J. Orman .................................................................................................................... 65

THE EFFECT OF THE DISTRIBUTION OF STATIC STRENGTH AND FATIGUE
LIFE ON THE DESTRUCTION OF A FIBER COMPOSITE USING THE MARKOV
CHAINS THEORY
R. Chatys .............................................................................................................................................. 66

DETERMINATION OF THE SIZE OF THE REPRESENTATIVE VOLUME
ELEMENT FOR THE ELASTOPLASTIC BEHAVIOR ANALYSIS OF POROUS
METAL STRUCTURES
Y. J. Cho, S. O. Yim, I. M. Park, and Y.H. Park ................................................................................. 67

A STUDY ON FLEXURAL PROPERTIES OF SANDWICH STRUCTURES WITH
FIBER/METAL LAMINATES FACE SHEETS
S. Dariushi and M. Sadighi .................................................................................................................... 68

CYCLIC VISCOELASTICITY AND VISCOPLASTICITY
OF POLYPROPYLENE/CLAY NANOCOMPOSITES
A. D. Drozdov, J. de C. Christiansen, and A.-L. Hog Lejre ................................................................. 69

ALIPHATIC POLYAMIDE– 66 HIGH-FILLED WITH
ALUMINIUM OXIDE FIBERS
V. I. Dubkova, N. P. Krutko, L. V. Ovseenko, and V. G. Komarevich ........................................... 70

DESIGN AND FABRICATION OF COPPER AND HYBRID EPOXY COMPOSITE
MATERIAL BY USING THE HAND LAY-UP TECHNIQUE
S. Duraisamy and K. Arumugam ........................................................................................................... 71

PROGRESS IN HIGH-PERFORMANCE CONTINUOUS NANOFIBERS FOR
STRUCTURAL NANOCOMPOSITES
Yu. Dzenis ................................................................................................................................................ 72

EFFECTIVE EQUATIONS FOR COMPOSITES WITH VISCOELASTIC AND
PLASTIC COMPONENTS
M. E. Eglitand T. A. Yakubenko ............................................................................................................ 73
PROGRESSIVE FAILURE ANALYSIS APPLIED TO E-GLASS FIBRE REINFORCED POLYMERS
B. Ellul and D. Camilleri ................................................................. 74

EXPERIMENTAL AND THEORETICAL STUDY OF THE ENERGY ABSORPTION CAPABILITY OF FABRIC AND COMPOSITE ARMOUR MATERIALS
A. F. Ermolenko and E. F. Kharchenko ........................................... 75

ON THE USE OF NON-NEWTONIAN QUASI-VISCOUS LIQUID DISPERSE MEDIA IN FABRIC AND COMPOSITE ARMOUR STRUCTURES (LIQUID ARMOUR)
A. F. Ermolenko ............................................................................. 76

ZINC OXIDE (ZNO), MAGNESIUM HYDROXIDE [MG(OH)₂] AND CALCIUM CARBONATE (CACO₃) NANO-POWDER-FILLED HDPE POLYMER COMPOSITES: MECHANICAL, THERMAL AND MORPHOLOGICAL PROPERTIES
S. Ersoy and M. Taşdemir ................................................................ 77

THERMAL BEHAVIOR OF COMPOSITES CONTAINING CARBON FIBERS OR CARBON NANOTUBES UNDER CRYOGENIC THERMAL CYCLING
L. E. Evseeva and S. A. Tanaeva ................................................... 78

THERMO-HYDRO-MECHANICAL MODELING OF POLIMER-MATRIX COMPOSITE BRAKE PAD MATERIALS
B. Fekete and A. Szekeres ................................................................ 79

ANALYSIS OF THE MECHANICAL PROPERTIES OF NANOFILLED EPOXY COMPOSITES
J. A. M. Ferreira, A. M. S. Pereira, P. N. B. Reis, and J. D. M. Costa ...................................................... 80

MODERN METHODS OF PROGRESSIVE FAILURE ANALYSIS OF COMPOSITE STRUCTURES USING MSC. SOFTWARE
L. Firsov, R. Gadelev, A. Leonov, and A. Safonov ........................................ 81

PROCESSING–STRUCTURE–PROPERTY RELATIONSHIPS OF THERMOPLASTIC NANOCOMPOSITES USED IN FRICTION AND WEAR APPLICATIONS
K. Friedrich, N. Knör, and A. A. Almajid ........................................ 82

FATIGUE AND DAMAGE TOLERANCE OF COMPOSITE BONDED JOINTS WITH 3D METALLIC REINFORCEMENT FEATURES
D. Furfari, C. Bisagni, and M. Pacchione ........................................... 83

PREPARATION AND PROPERTIES OF NANOCOMPOSITES FROM POLYURETHANE REINFORCED WITH MONTMORILLONITE
S. Gaidukov, K. Gromilova, R. D. Maksimov, V. Titureina, U. Cabulis, and A. Fridrihsoone ......................................................... 84

ASSESSMENT OF THE FATIGUE LIFE OF A TOWER BY USING A REAL-TIME LOADING HISTORY
L. Gaile and I. Radinsh .................................................................... 85

THERMOMECHANICAL PROPERTIES OF POLYLACTIC ACID/WOOD FLOUR COMPOSITES
P. Georgiopoulos, E. Kontou, and N. Antonakopoulos .................................................. 86
PREDICTION OF IN THE REDUCTION SHEAR MODULUS DUE TO TRANSVERSE CRACKING
K. Giannadakis and J. Varna ........................................................................................................ 87

MECHANICAL PROPERTIES OF EPOXY AND AN EPOXY-BASED CFRP FILLED WITH CARBON NANOTUBES
T. Glaskova, A. Aniskevich, M. Zarrelli, A. Martone, and M. Giordano ................................. 88

OPTIMAL DESIGN OF COMPOSITE WING BOX STIFFENED PANELS PROVIDING STRENGTH AND STABILITY
S. Gluhih, O. Mitrofanov, and A. Sorokin ................................................................................ 89

POSTBUCKLING-STATE-ASSISTED DESIGN OF COMPOSITE DEVICE PANELS BY TAKING INTO ACCOUNT THE FATIGUE LIFE AND RESIDUAL STRENGTH BOUNDARY CONDITIONS
S. Gluhih, O. Mitrofanov, and A. Sorokin ................................................................................ 90

IDENTIFICATION OF THE OUTER-LAYER MODULUS OF A TWO LAYER POLYMER CYLINDRICAL SHELL
S. Gluhih, A. Kovalovs, and A. Chate ...................................................................................... 91

DESIGN OF CARBON-NANOTUBE-REINFORCED ALUMINUM-MATRIX COMPOSITES
J.-K. Gomon, L. Kommel, L. Kollo, J. Majak, R. Metsvahi, and M. Mihhaltsenkov .......... 92

ANALYSIS OF HYBRID COMPOSITE CABLE FOR PRESTRESSED SUSPENSION BRIDGE
V. Goremikins, K. Rocens, and D. Serdjuks ............................................................................. 93

QUASISTATIC AND DYNAMIC MECHANICAL PROPERTIES OF POLYOXYMETHYLENE AND ETHYLENE-OCTENE COPOLYMER COMPOSITES
A. Grigaloviča, M. Bartule, J. Zicans, Ch. Berger, and H.-P. Heim ...................................... 94

INVESTIGATION OF BOND BETWEEN GFRP BARS AND CONCRETE
E. Gudonis, A. Weber, V. Gribniak, R. Jakubovskis, and G. Kaklauskas ................................. 95

INTERCONVERSION OF VARIATIONAL EQUATIONS IN A COMPARATIVE FUNCTIONAL ANALYSIS OF SPECIFIED MODELS OF LAYERED PLATES
O. G. Gurtovy ......................................................................................................................... 96

FIRE RESISTANCE OF 3D SYSTEM CEILING PANEL
R. Haddad and R. Alrousan ..................................................................................................... 97

INTERACTION BETWEEN CIRCULAR HOLES IN A PRESTRETCHED ANISOTROPIC PLATE-STRIP UNDER PRESSURE
E. Hazar, M. Eröz, E. Nart, and I. Arda .................................................................................. 98

SMART COMPOSITE SANDWICH STRUCTURES BASED ON ELECTROACTIVE POLYMERS
M. Henke, J. Sorber, and G. Gerlach ..................................................................................... 99

ANALYSIS OF A CARBON-FIBER COMPOSITE WITH EMBEDDED ELECTRONICS
H. Herranen, J. S. Preden, J. Kers, J. Majak, M. Pohlak, M. Eerme, A. Aruniit,
H. Lend, and G. Allikas .......................................................................................................... 100
ASSESSMENT OF THE STABILITY OF A SURFACE CRACK IN LAMINATES
  P. Hutař, M. Ševčík, L. Náhlík, and Z. Knésl ................................................................. 101

EXPERIMENTAL AND THEORETICAL INVESTIGATION OF DEFORMATION
AND FRACTURE OF HUMAN BODY FAT UNDER COMPRESSION
  A. V. Ignatova and S. B. Sapožnikov .................................................................................. 102

STRUCTURE AND MECHANICAL PROPERTIES OF CELLULOSE
NANOCRYSTALLITES
  M. Ioelovich and O. Figovsky ......................................................................................... 103

DEFLECTION AND CRACKING ANALYSIS OF GFRP-REINFORCED BEAMS
BASED ON THE STRESS TRANSFER APPROACH
  R. Jakubovskis, G. Kaklaukas, V. Gribniak, A. Weber, and M. Juknys ............................ 104

INVESTIGATION OF THE MECHANICAL PROPERTIES OF WELL-DISPERSED
AL-CNT COMPOSITES PREPARED BY THE MODIFIED MECHANICAL
ALLOYING METHOD
  A. H. Javadi, Sh. Mirdamadi, M. A. Faghihisani, and S. Shakhesi .................................. 105

MECHANICAL PROPERTIES OF A RAPIDLY PROTOTYPED COMPOSITE:
NUMERICAL MODELING AND PARAMETRIC ANALYSIS
  N. Jekabsons, U. Locans, and R. Joffé ............................................................................. 106

VIBRATION OF ANISOTROPIC STEPPED PLATES WITH CRACKS
  E. Kägo and J. Lellep ........................................................................................................... 107

STRESS-STRAIN AND CRACK WIDTH ANALYSIS OF TENSILE SFRC
MEMBERS
  G. Kaklaukas, V. Gribniak, A. Meskenas, and R. Jakubovskis ........................................ 108

NUMERICAL ESTIMATION OF FIRE-RESISTANCE AND FLEXIBLE DESIGN
OF FIRE PROTECTION FOR STRUCTURES OF REINFORCED MATERIALS
  V. O. Kaledin, A. B. Mitkevich, and V. L. Strakhov ....................................................... 109

COMPRESSIVE STRENGTH OF CONCRETE WITH A GROUND GRANULATED
BLAST FURNACE SLAG
  P. Kara, A. Korjakins, and R. Gulbis .................................................................................. 110

THE USAGE OF A WASTE GLASS POWDER AS A MICROFILLER IN UHPC
  P. Kara, A. Korjakins, and K. Kovalenko ........................................................................... 111

MECHANICAL PROPERTIES OF HEMP-FIBRE-CONCRETE STRUCTURAL
ELEMENTS
  P. Kara, A. Korjakins, and K. Kuznecovs ............................................................................ 112

HIGH-EFFICIENCY NANOCONCRETE CONTAINING LOCAL INDUSTRIAL BY-
PRODUCTS AND WASTES
  P. Kara, A. Korjakins, and G. Shakhmenko ........................................................................ 113

THE EFFECT OF MINERAL ADMIXTURES SUCH AS COAL AND WOOD ASHES ON THE COMPRESSIVE STRENGTH OF CONCRETE
  P. Kara, A. Korjakins, and V. Stokmanis-Blaus ................................................................. 114

INFLUENCE OF CRACKS AND MATERIAL MICROSTRUCTURE ON
AN INTERFACE CRACK IN FUNCTIONALLY GRADED/ HOMOGENEOUS
COMPOSITE BIMATERIALS SUBJECTED TO ANTIPLANE LOADING
  N. Karaulova and V. Petrova ............................................................................................... 115
NUMERICAL MODELING OF SINGLE STEEL FIBER PULL OUT OF CONCRETE
O. Kononova, A. Krasnikovs, A. Galushchak, V. Zaharevsky, and E. Machanovsky ...... 116

CARBON NANOTUBES AS MODIFIERS OF EPOXY-POLYSULFONE MATRICES FOR UNIDIRECTIONAL ORGANIC-FIBER-REINFORCED PLASTICS

ANALYSIS OF THE SHEAR STRENGTHENED OF A RC FRAME WITH NEAR-SURFACE MOUNTED FRP BARS
A. Kosarian and M.-K. Sharbatdar ........................................................................... 118

THE INFLUENCE OF INTERACTION BETWEEN PERIODICALLY LOCATED ROWS OF FIBERS IN A COMPOSITE MATERIALS ON THE DISTRIBUTION OF STRESSES
R. Kosker, S. D. Akbarov, and Y. Ucan ................................................................. 119

NANOTRIBOLOGY AND MICROMECHANICS OF POLYSTYRENE-NANOCLAY COMPOSITES
S. V. Kotomin, I-Ta Chang, E. Sancaktar, and D. Iarikov ............................................. 120

MECHANICAL PROPERTIES OF HYBRID LAMINATES CONSISTING OF CFRP AND RUBBER-CORK LAYERS
R. Kottner, J. Vacík, R. Zemčík, and J. Krystek ......................................................... 121

OPTIMAL DESIGN AND EXPERIMENTAL VERIFICATION OF A FULL-SCALE COMPOSITE ROTOR BLADE WITH MACROFIBER COMPOSITE ACTUATORS
A. Kovalovs, E. Barkanov, and S. Gluhihs ................................................................ 122

EFFECT OF MOISTURE ON THE MATERIAL PROPERTIES OF A COMPOSITE MATERIAL
A. Kovalovs, P. Serebrjakovs, and A. Sorokins ......................................................... 123

POLYMER COMPOSITE PIPES FOR ENGINEERING NETWORKS
V. Kovriga ................................................................................................................. 124

THERMAL STUDY OF A MODIFIED POLYURETHANE DISPERSION FOR LEATHER SURFACE DYEING
O. Kovtunenko, T. Travinskaya, and V. Plavan ......................................................... 125

COMPOSITE MATERIAL REINFORCED BY A KNITTED FABRIC. PREDICTION OF ITS STRENGTH AND ELASTIC PROPERTIES AND EXPERIMENTAL VALIDATION
A. Krasnikovs, O. Kononova, G. Harjkova, V. Zaharevsky, E. Machanovsky, S. Ruchevskis, and P. Akishins ................................................................. 126

MECHANICAL PROPERTIES OF A LAYERED FIBERCONCRETE STRUCTURE
A. Krasnikovs, V. Lapsa, V. Lusis, V. Zaharevsky, E. Machanovsky, and G. Harjkova ................................................................. 127

THIN CONCRETE SHELLS REINFORCED WITH GLASS FIBERS. MANUFACTURING TECHNOLOGY AND MECHANICAL PROPERTIES
A. Krasnikovs, V. Lapsa, V. Lusis, V. Zaharevsky, and E. Machanovsky .......... 128

DEFORMATION AND STRENGTH OF LAMINATED CARBON-FIBER-REINFORCED PLASTICS UNDER STATIC THERMOMECHANICAL LOADING
N. K. Kucher, M. N. Zarazovskii, and E. L. Danil’chuk ........................................ 129
EFFECT OF YBa$_2$Cu$_3$O$_{6.7}$ FILLER CONTENT ON THE PHYSICAL AND MECHANICAL PROPERTIES OF A POLYIMIDE COMPOSITE MATERIAL
A. I. Kupchishin, A. D. Muradov, and B. G. Taipova .......................................................... 130

EFFECT OF GAMMA-RADIATION ON CHANGES IN THE REFRACTION OF “POLYIMIDE -YBa$_2$Cu$_3$O$_{6.7}$” COMPOSITE MATERIALS
A. I. Kupchishin, A. D. Muradov, B. G. Taipova, G. B. Sarsembayev, and B. A. Kozhamkulov .......................................................... 131

COMPOSITE CONCRETE-FILLED TUBULAR MEMBERS IN TENSION
A. K. Kvedaras, A. Šapalas, and J. Katinas .......................................................... 132

SIMULATION OF THE MECHANICAL BEHAVIOR OF SANDWICH PANELS WITH A DENDROLOGIT® CELLULAR WOOD-MATERIAL CORE
E. Labans and K. Kalniņš .......................................................... 133

USE OF NANOPARTICLES OBTAINED FROM WOOD PROCESSING RESIDUES FOR REINFORCING PAPER
M. Laka, S. Chernyavskaya, A. Treimanis, and M. Skute .......................................................... 134

CONTROL OF CONTACT ANGLE ON COMPOSITE SURFACE BY THERMAL EXPANSION
Ch. Lee and W. Hwang .......................................................... 135

MECHANICAL TESTING OF PROTOTYPES OF ROAD SAFETY BARRIERS MADE FROM REINFORCED POLYETHYLENE
V. Leitlands and N. Viderkers .......................................................... 136

AXISYMMETRIC VIBRATIONS OF ORTHOTROPIC CIRCULAR CYLINDRICAL SHELLS WITH CRACKS
J. Lellep and L. Roots .......................................................... 137

THE DEVELOPMENT OF KNIFE- AND BULLET-IMPACT-RESISTANT COMPOSITE STRUCTURES
A. A. Levinsky, S. B. Sapozhnikov, and T. S. Grass .......................................................... 138

IMPACT ESTIMATION OF EXTERNAL ACTUATING FACTORS AND OPERATIONAL CONTAMINATION ON THE OPERATIONAL CAPABILITY OF FIBROUS POLYMER COMPOSITE MATERIALS.
D. Lobanov, V. Vildeman, A. Babin, and M. Grinev .......................................................... 139

IMPROVING THE STRUCTURAL PERFORMANCE OF ADVANCED COMPOSITES WITH NON-CONVENTIONAL LAMINATES
C. S. Lopes, Z. Gürdal, and P. P. Camanho .......................................................... 140

APPLICATION OF ELECTRONIC SPECKLE PATTERN INTERFEROMETRY (ESPI) TECHNIQUE FOR DAMAGE CHARACTERIZATION IN LAMINATES
M. S. Loukil and Z. Ayadi .......................................................... 141

THERMO-ELASTIC PROPERTIES OF NON-UNIFORMLY DAMAGED LAMINATES AT HIGH CRACK DENSITY
M. S. Loukil, J. Varna, and Z. Ayadi .......................................................... 142

FABRICATION OF A SUPERHYDROPHOBIC SURFACE HAVING DRAG REDUCTION EFFECTS
S. Lyu, D. C. Nguyen, B. S. Yoon, and W. Hwang .......................................................... 143
NONLOCAL ELASTICITY APPROACH TO THE VIBRATION ANALYSIS OF GRAPHENE SHEETS
J. Majak, M. Pohlak, M. Eerme, K. Karjust, and J. Kers ................................................. 144

DETERMINATION OF MICRO-CRACK PATH IN PARTICULATE COMPOSITE
Z. Majer, P. Hutař, and L. Náhlík ......................................................................................... 145

FEATURE-BASED METHOD IN THE APPLICATION OF STRUCTURAL COMPOSITES - EXPERIMENTAL SYNTHESIS AND ANALYSIS
M. Majzner and A. Baier ......................................................................................................... 146

ULTRASTRONG/TOUGH CONTINUOUS DNA NANOFILAMENTS FOR NOVEL HIERARCHICAL BIOMATERIALS AND COMPOSITES
K. Maleckis and Yu. Dzenis .................................................................................................. 147

SERVICE LIFE ASSESSMENT AND MOISTURE INFLUENCE ON COMPOSITES FROM RENEWABLE FEEDSTOCK
P. Mannberg, L Rozite, R. Joffè, and B. Nyström ................................................................. 148

METHOD OF INVESTIGATION OF LAYERED COMPOSITES WITH INTERPHASE IMPERFECTIONS AND DAMAGED LAYERS
M. Marchuk, V. Kharchenko, and M. Khomyak .................................................................. 149

FREE VIBRATIONS OF A TWO-LAYERED PLATE-STRIP WITH COMPOSITE COMPONENTS PLIABLE IN TRANSVERSE SHEAR AND COMPRESSION
M. Marchuk, V. Pakosh, and O. Lesyk .................................................................................. 150

INTERFACIAL FAILURE IN COMPOSITES UNDER OFF-AXIS LOADING
Ch. Marotzke ......................................................................................................................... 151

PARTICULATE COMPOSITE MATERIALS: NUMERICAL MODELLING OF CROSS-LINKED POLYMER REINFORCED BY ALUMINA BASED PARTICLES
B. Máša, L. Náhlík, and P. Hutař ......................................................................................... 152

DETERMINATION OF STRESS-CRACK OPENING RELATIONSHIP OF SFRC BY INVERSE ANALYSIS
A. Meskenas, G. Kaklauskas, V. Gribniak, D. Bacinskas, and V. Gelazius........................... 153

ACYRLONITRILE BUTADIENE STYRENE/HIGH DENSITY POLYETHYLENE COMPOSITES FROM WASTE SOURCES BY USING COUPLING AGENTS
N. Miskolczi, V. Sedlarik, P. Kucharczyk, and H. Szakacs .................................................... 154

EVALUATION OF IFSS IN SHORT-FLAX-FIBER/PP COMPOSITES
J. Modniks, E. Poriķe, and J. Andersons ............................................................................... 155

ENHANCING THE THERMOMECHANICAL PROPERTIES OF AN EPOXY/CARBON FIBER NANOCOMPOSITES USING BY NANOREINFORCEMENTS
E. S. Molchanov, V. E.Yudin, and K. A. Kydralieva ............................................................... 156

CORROSION OF STEEL IN HIGH-STRENGTH CONCRETE
R. Moldovan, C. Magureanu, and C. Negrutiu .................................................................... 157

INFLUENCE OF TIME ON THE SERVICEABILITY LIMIT STATE FOR HSC BEAMS SUBJECTED TO BENDING
A. Muntean, C. Măgureanu, and G. Bărboș ........................................................................ 158

CONTACT MECHANICS AND TRIBOLOGY OF POLYMER COMPOSITES
N. K. Myshkin .................................................................................................................... 159
PHYSICAL AND MECHANICAL PROPERTIES OF COMPOSITES BASED ON A LINEAR LOW-DENSITY POLYETHYLENE (LLDPE) AND NATURAL FIBRE WASTE
O. Nestore, J. Kajaks, and S. Reihmane

FRICITIONLESS INDENTATION OF A FUNCTIONALLY GRADED VITREOUS ENAMELED STEEL PLATE BY A RIGID SPHERICAL INDENTER
A. Nikbakht, M. Sadighi, and A. Fallahi Arezooedar

SPRINGBACK ANGLE OF A C/PPS LAMINATE WITH TEXTILE REINFORCEMENT
Z. Padovec and M. Růžička

MARKOV MODEL OF FATIGUE OF A COMPOSITE MATERIAL WITH POISSON PROCESS OF DEFECT INITIATION
Yu. Paramonov, R. Chatys, J. Andersons, and M. Kleinhofs

PROPAGATION OF THE ULTRASONIC GUIDED WAVE IN A COMPOSITE PLATE: SOME RESULTS OF SIMULATION AND TEST
I. Pavelko, V. Pavelko, and M. Smolyaninov

IMPACT OF COMPOSITE COMPONENT OF AIRCRAFT AND ITS DAMAGE
I. Pavelko, V. Pavelko, and M. Smolyaninov

CHANGE IN THE SHEAR STIFFNESS OF 3D-REINFORCED CARBON PLASTICS AT A LOW-VELOCITY IMPACT
I. Pavelko, M. Smolyaninov, and V. Zhigun

STRESS STATE AND STRENGTH OF PIEZOCERAMICS UNDER A STATIC LOAD
V. Pavelko, I. Pavelko, and S. Kuznetsov

FRACTURE OF FUNCTIONALLY GRADED/ HOMOGENEOUS BIMATERIALS WITH AN INTERFACE CRACK AND SYSTEMS OF CRACKS UNDER THERMAL AND MECHANICAL LOADING
V. Petrova and S. Schmauder

POLYPROPYLENE (PP) BASED CONDUCTIVE COMPOSITES REINFORCED WITH EXPANDED GRAPHITE (EG) VIA EXTRUSION AND COMPRESSION MOULDING
J. Pionteck, F. Piana, and E. Melchor

ANALYSIS OF THE STRESS-STRAIN STATE OF LAMINATED CYLINDRICAL SHELLS UNDER A LOCAL LOADING BY A SEMI-ANALYTIC FINITE ELEMENT METHOD
V. G. Piskunov, A. V. Marchuk, and S. V. Gnedash

MODELLING AND INVESTIGATION OF ADVANCED PIEZO COMPOSITE MFC ACTUATOR APPLICATION
M. Płaczek

SOME FUNCTIONAL PROPERTIES OF A COMPOSITE MATERIAL BASED ON SCRAP TIRES
R. Plesuma, A. Megne, I. Mateusa-Krukle, and L. Malers

WAVE TRANSMISSION IN HOLLOW ANISOTROPIC SPHERICAL SHELL SUBMERGED IN AN INCOMPRESSIBLE LIQUID
V. Polyakov
HYPETROPHY OF SKELETAL MUSCLES AND AN OVERWEIGHT DISTINCTION METHOD IN ATHLETES
I. Pontaga

SCALE EFFECT OF THE TENSILE STRENGTH OF ELEMENTARY HEMP FIBERS
E. Poriķe

GRIPPING DEVICE FOR TRANSMISSION OF TENSILE LOAD TO FRP STRIP
G. Portnov, V. Kulakov, and A. Arnaoutov

FIBER/MATRIX INTERFACE DEBOND GROWTH IN THE VICINITY OF THE SURFACE OF A UD COMPOSITE SUBJECTED TO CYCLIC LOADING
A. Pupurs and J. Varna

NATURAL HEMP FIBRE AS ADDITIVES TO FORM POLYMER COMPOSITES
A. Putnina, S. Kukle, and J. Gravitis

SYNTHESIS OF THE MAXWELL MODEL BASED ON NANOPARTICLES
M. A. Ramazanov and M. S. Aslanov

THE EFFECT OF A UNIFORM MAGNETIC FIELD AND RADIATION MODIFICATION ON THE MECHANICAL PROPERTIES OF BLENDS OF A HIGH-DENSITY POLYETHYLENE WITH CHLORINATED POLYETHYLENE
I. Reinholds, V. Kalkis, and R. D. Maksimov

HYGROTHERMAL EFFECT ON THE IMPACT RESPONSE OF CARBON COMPOSITES WITH EPOXY RESIN ENHANCED BY NANOCLAYS
P. N. B. Reis, A. P. Silva, P. Santos and J. A. M. Ferreira

APPLICATION VALUE OF FRACTURE TOUGHNESS TO THE EVALUATION OF THE QUALITY OF A BUTT FUSION JOINT OF POLYETHYLENE PIPES REINFORCED WITH ALUMINA-BASED PARTICLES
A. K. Rodionov, F. I. Babenko, and Y. Y. Fedorov

SPRING-IN AND WARPAGE – PROGRESS IN SIMULATING MANUFACTURING ASPECTS
K. Rohwer, E. Kappel, D. Stefaniak, and T. Wille

VALIDATION OF A HEURISTIC FIBRE PLACEMENT ALGORITHM: STATISTICAL ANALYSIS OF REAL AND SIMULATED FIBRE ARRANGEMENTS
V. Romanov, S. V. Lomov, L. Gorbatikh, and I. Verpoest

ANALYSIS OF THE NONLINEAR BEHAVIOR OF BIO-BASED POLYMERS REINFORCED WITH FLAX FIBERS
L. Rozite and R. Joffe

ANALYSIS OF THE TIME-DEPENDENT BEHAVIOR OF BIO-BASED COMPOSITES MADE FROM HIGHLY NON-LINEAR CONSTITUENTS
L. Rozite, R. Joffe, J. Varna, and B. Nyström

ESTIMATION OF THE QUALITY OF ANTICORROSIVE MULTICOMPONENT POLYMERIC COATINGS OF TECHNOLOGICAL EQUIPMENT FOR GASFIELDS OF JSC "GAZPROM"
J. S. Ryabets, N. V. Sorokina, and S. A. Soloviev
APPLYING OF PROBABILISTIC METHODS TO THE MATHEMATICAL SIMULATION OF TECHNOLOGICAL DEFECTS ARISING IN VACUUM INFUSION OF PRODUCTS MADE OF COMPOSITE MATERIALS

A. Safonov .................................................................................................................. 188

THE INFLUENCE OF INHOMOGENEITY OF A GLASS-FIBER CHOPPED STRAND MAT ON THE LOCAL STRENGTH AND STIFFNESS OF A COMPOSITE

S. B. Sapozhnikov and A. V. Bezmelnitsyn .................................................................. 189

DELAMINATION OF COMPOSITE THICK-WALLED RINGS UNDER BENDING

S. Sapozhnikov and A. Shcherbakova ........................................................................... 190

OPTIMIZATION OF THE STACKING-SEQUENCE OF LAMINATED COMPOSITE PLATES UNDER BUCKLING LOADS

J. Sedyono, H. Hadavinia, J. Deng, D. R. Marchant, and J. Garcia ............................. 191

BENDING BEHAVIOUR OF STRUCTURAL GLASS WITH DIFFERENT INTERLAYER LAMINATES

T. Serafinavicius, A. K. Kvedaras, and G. Sauciuvenas .............................................. 192

PREDICTION OF STRAIN AND STRENGTH PARAMETERS OF ASPHALT CONCRETE

S. V. Shilko ................................................................................................................... 193

STUDY OF THE POLYELECTROLYTE COMPLEX BETWEEN ASPEN LIGNIN AND POLYETHYLENIMINE

G. Shulga, S. Vitolina, A. Verovkins, B. Neiberte, J. Brovkina, and S. Ostrovska ......... 194

COMPARATIVE EFFECT OF POLYALUMINIUM CHLORIDE AND ITS COMPOSITION WITH SULPHATE ALUMINIUM ON WOOD PROCESSING WASTEWATER COAGULATION


HYBRID-FIBRE-REINFORCED CEMENTITIOUS COMPOSITES

E. R. Silva, J. F. J. Coelho, and J. C. Bordado .............................................................. 196

PREDICTION OF THE FLEXURAL BEHAVIOUR OF STEEL FIBER REINFORCED CONCRETE

U. Skadiņš and J. Brauns ............................................................................................. 197

DYNAMICS OF COMPOSITE LATTICE PAYLOAD ADAPTER

A. Skleznev .................................................................................................................. 198

RESIDUAL STRESS IN MOISTURE-SENSITIVE LAMINA

J. Šliseris and K. Rocēns .............................................................................................. 199

COMPARISON OF FRACTURE ENERGIES OF EPOXYPOLYSULFONE MATRICES AND UNIDIRECTIONAL COMPOSITES BASED ON THESE MATRICES

V. I. Solodilov, R. A. Korokhin, Yu. A. Gorbatkina, and A. M. Kuperman ................. 200

MECHANICAL AND RHEOLOGICAL PROPERTIES OF THERMOPLASTIC ELASTOMERS WITH A RUBBER POWDER

D. V. Solomatkin, O. P. Kuznetsova, and E. V. Prut .................................................. 201
FINITE ELEMENT ANALYSIS OF THE INTERFACIAL FRACTURE TOUGHNESS OF HONEYCOMB SANDWICH BEAMS FROM TILTED SANDWICH DEBOND TESTS
W. Song and Z. J. Ma.......................................................... 202

STIFFNESS, STRENGTH, AND TOUGHNESS CHARACTERISTICS OF A UNIDIRECTIONAL FLAX-FIBER COMPOSITE
E. Spārnīš, J. Modnīks, and J. Andersons .................................. 203

EXPERIMENTAL STUDY ON THE EARLY-AGE CREEP AND SHRINKAGE OF PVA FIBER-REINFORCED HIGH STRENGTH CONCRETE
A. Sprince, L. Pakrastins, A. Korjakins, G. Shakhmenko, and G. Bumanis........................................... 204

EFFECT OF NANOTUBE ADDITION ON TENSILE, THERMAL AND TRANSPORT PROPERTIES OF POLY(ETHYLENE-VINYL ACETATE) COPOLYMERS

STRENGTH – DEFORMATION CHARACTERISTICS OF SLIGHTLY CROSSLINKED POLY(VINYL ALCOHOL) GELS
J. Stasko, L. Berzina – Cimdina, and M. Kalnins ................................................................. 206

INTELLIGENT CHARACTERIZATION OF MATERIALS BY USING MACHINE INTELLIGENCE
V. Shtrauss, A. Kalpinsh, and U. Lomanovskis................................................................. 207

SELF-MONITORING OF FIBRE-REINFORCED COMPOSITES: VISUAL RESPONSE TO THE EXTERNAL INDENTATION
O. Strekalova, S. Vidinejevs, and A. Aniskevich................................................................. 208

THE S-N EQUATIONS OF TYPICAL AIRFRAME COMPOSITE ELEMENTS
V. Strizhius..................................................................................... 209

NONLINEAR TRANSIENT ANALYSIS OF SANDWICH PLATES WITH PARABOLICALLY VARYING THICKNESS
S. Susler, H. S. Turkmen, and Z. Kazanci............................................................. 210

TAILORING OF COMPOSITES BY USING THermo-HYgro-MECHANICS (THM) (BROADENING THE POSSIBILITY BY GENERALIZING FROM TS -> TM -> THM)
A. Szekeres and B. Fekete........................................................................... 211

STUDIES OF MANUFACTURING DEFECTS FOR COST-EFFECTIVE PERFORMANCE OF COMPOSITE STRUCTURES
R. Talreja..................................................................................... 212

INFLUENCE OF FIBERS ORIENTATION AND VOLUME CONTENT ON THE FRACTURE OF FIBER-REINFORCED CONCRETE
S. Tarasovs, E. Zile, and V. Tamužs........................................................................ 213

MONITORING THE CURE OF EPOXY RESINS WITH DIFFERENT METHODS
G. Teteris, U. Braun, and W. Stark........................................................................ 214

EFFECT OF SMALL CONCENTRATIONS OF MULTIWALL CARBON NANOTUBES ON MECHANICAL AND TERMOPHYSICAL PROPERTIES OF EPOXY NANOCOMPOSITE
K. Timchenko, A. Bondon, T. Glaskova, and A. Borisova........................................... 215
TENSION STIFFENING IN CONCRETE BEAMS WITH A COMPOSITE REINFORCEMENT
E. Timinskas, V. Gribniak, G. Kaklauskas, A. Weber, and R. Jakubovskis ........................... 216

EFFECT OF IONIZING RADIATION ON THE THERMAL CONDUCTIVITY OF LAMINATE
K. B. Tlebaev and A. I. Kupchishin ................................................................. 217

ADHESION MECHANICS (ADHESION JOINTS AND DISCRETE MODELS OF COMPOSITES. CONTACT LAYER METHOD)
R. A. Turusov and L. I. Manevich ................................................................. 218

DEVELOPMENT OF A HIGHLY STRESSED BLADED ROTOR MADE OF CFRP
BY USING TAILORED FIBRE PLACEMENT TECHNOLOGY
K. Uhlig, A. Spickenheuer, and G. Heinrich ........................................ 219

REFRACTORY OXIDE POWDERS AND CERAMIC COMPOSITES BASED ON THEM
T. M. Ulyanova, L. V. Titova, N. P. Krutko, A. A. Shevchonok, and A. R. Luchenok .... 220

RESEARCH INTO THE MICROMECHANICS OF THE PLASTIC-ELASTIC BEHAVIOUR OF ANISOTROPIC COMPOSITE MATERIALS UNDER STATIC LOADING BY THE ACOUSTIC EMISSION METHOD
A. Urbach, M. Banov, V. Turko, K. Savkov, Y. Feshchuk , and K. Carjova .................. 221

RESEARCH ON THE SERVICE PROPERTIES OF INTERMETALLIC COATINGS FOR THE BLADES OF AERO-ENGINE TURBINES ON THE BASIS OF TITANIUM-ALUMINIUM
A. Urbach, K. Savkov, M. Urbaha, and G. Rijkuris ........................................... 222

EXPERIMENTAL EVALUATION OF THE HARDNESS AND ELASTIC PROPERTIES OF WEAR-RESISTANT NANOSTRUCTURAL ION-PLASMA COATINGS BY NANOINDENTATION
M. Urbaha, A. Urbahs, and K. Savkovs ......................................................... 223

INFLUENCE OF THE SURFACE FINISH QUALITY OF REINFORCEMENT ON THE RESISTANCE OF COMPOSITES TO OPERATIONAL FACTORS
A. E. Ushakov, Y. G. Klenin, T. G. Sorina, T. V. Penskaya, and A. V. Sokolova...... 224

INFLUENCE OF CARBON NANOTUBES (CNTS) AND METAL SALTS IN THE NANOFORM ON THE STRUCTURE OF A POLYMER MATRIX AND ON THE PROPERTIES OF POLYMER MATRIX-BASED COMPOSITES
A. E. Ushakov, Y. G. Klenin, T. G. Sorina, T. V. Penskaya, and K. G. Kravchenko .... 225

THE MODELING OF CREEP FOR POLYMER-BASED NANOCOMPOSITES
BY USING AN ALTERNATIVE NONLINEAR OPTIMIZATION APPROACH
I. Viktorova, B. Dandurand, S. Alexeeva, and M. Fronya ........................................ 226

INFLUENCE OF SELECTED PARAMETERS OF DRAWING PROCESS ON THE EXPANSIVE DEPOSITION OF THE INNER PE LINING IN PIPELINES
G. Wróbel, M. Szymiczek, and M. Rojek .......................................................... 227

PROPERTIES OF RIGID POLYURETHANE FOAMS FILLED WITH GLASS MICROSPHERES
V. Yakushin, L. Belkova, and I. Sevastyanova .................................................. 228

COUPLED QUASI-HOMOGENEOUS ANISOTROPIC LAMINATES
C. B. York ........................................................................................................... 229
COMPARATIVE ANALYSIS OF THE ENTIRE MANUFACTURE PROCESS OF COMPOSITE FILLERS FOR SANDWICH PANELS
A. Zaharov

THERMOMECHANICAL BEHAVIOR OF FLEXIBLE GRAPHITE O-RING SEALS UNDER THEIR EXPLOITATION IN STOP VALVES
A. V. Zaitsev, O. Yu. Isaev, D. S. Rogov, D. M. Karavaev, and D. V. Smirnov

PROBABILISTIC METHODS FOR THE ANALYSIS OF RANDOM STRUCTURES, STRESS AND STRAIN FIELDS IN 2D AND 3D MATRIX-INCLUSION COMPOSITES, HIGH-POREUS METALLIC FOAMS AND BONES
A. V. Zaitsev, A. V. Kislitsyn, V. S. Koksharov, Ya. K. Pokataev, and Yu. V. Sokolkin

DYNAMICAL STRAINED CONDITION OF A BI-LAYER PLATE ON A RIGID FOUNDATION
A. D. Zamanov and T. R. Suleymanov

BEAM BENDING WITH CONSIDERATION OF CORROSION WEAR
A. D. Zamanov and S. A. Gahramanov

ON THE ACCURACY OF THE “EQUIVALENT CYLINDER” APPROACH IN MEASURING THE LOCAL INTERFACIAL SHEAR STRENGTH IN THE PULL-OUT TEST
S. Zhandarov and E. Mäder

TESTING OF ABRASIVE WEAR OF FML COMPOSITES BASED ON A FIBREGLASS WOVEN FABRIC
S. J. Zolkiewski

STRENGTH PROPERTIES OF FIBRE-METAL LAMINATES CONNECTED BY SCREW JOINTS
S. J. Zolkiewski

AUTHORS INDEX
QUALITY ASSESSMENT OF A NUMBER OF SCREW-FIXED DAMAGES AT THE PARTICLE-BOARD SURFACE: VARIOS SCREW TYPES IN THREE DIFFERENT SCREW INSERTION TECHNIQUES

F. Abu and M. Ahmad

Faculty of Applied Science, Universiti Teknologi MARA, UiTM Shah Alam, Malaysia

Construction of kitchen cabinet in Malaysia has grown in corresponding with the increasing number (no.) of housing development. However, kitchen cabinet supplier facing a major problem regarding the increasing number of failure occurred at the screw jointing during kitchen cabinet installation as showed in Figure 1. The particleboard was inserting with 4M chipboard screw; a common chipboard screws causing the particleboard panel surfaces spoiled or chip off. Therefore, totally 375 screws within four alternative types of screws were tested using three different screw insertion techniques. The damages within each screw insertion at difference type of screw were analyzed. The variability for this objective is type of screw used and the technique of screw insertion. A minimum of twenty-five samples of each variable were cut from the panel (EN326-1). All prepared samples was conditioned into an air-conditioned room environment at 20°C Temp and 65% RH first. Then it was simulated to on-site kitchen environment in Malaysia at the 31.3°C and 72% in RH. Next, all the samples were inserted with screw according to its variability. The screw insertion was done at the face surfaces using variety type of screw with difference technique of insertion. Yet, all testing samples only covered by melamine at the face surface and not at the edge surface. All types of screw and insertion technique were discussed. From the result in no. of damage detected, the worst parameter was the No.8 CSK screw with self-drilling insertion. This screw probably was good for wood insertion but not for the particleboard type. With this paper, the kitchen cabinet manufacturer will be able to select the best screw with their preferable insertion technique in order to reduce the number of damages especially during screw insertion.

Fig. 1. Image of screw fixing inspected and damages on every kitchen cabinet installation.
The adsorption of glycine onto Diamond like carbon (DLC) and fluorine doped DLC thin films synthesised by Plasma Enhanced Chemical Vapour Deposition (PECVD) has been investigated using a range of surface analysis techniques. Effect of surface morphology, of the interaction of simplest amino acid (glycine) with modified hydrogenated amorphous carbon films has been studied. The chemical composition of the surface before and after adsorption was analysed using X-ray photoelectron spectroscopy (XPS) spectra show that peaks at 285 eV (C1s), 532 eV (O1s) and the band at 684 eV (F1s) in case of F-DLC samples.

Following exposure to solutions containing (0.001M) glycine, presence of peaks at ~285.0, ~399 and ~532 eV with reduces of band intensity at 684 eV with quantitative change of amount of C, N and O on the surfaces. A Fourier transform infrared (FTIR) spectrum was recorded at room temperature. The vibrational assignments of the observed wave numbers have been made for the functional groups, e.g. COO−R, COO¯, -NH3 +, NH2, C-H and C-C-N. The results from both XPS and FTIR spectroscopy confirm that glycine was bound to the surface of the DLC and F-DLC films via interaction of ionized carboxyl groups and the amino group did not play a significant role in the adsorption of glycine.

REFERENCES
Under consideration there are axisymmetric contact problems for the coated materials. It is supposed that elastic properties of coatings vary only on depth. Using a method of integral transformations, the solution of contact problems is reduced to the solution of the dual integral equations. Generally kernels’ transforms of these equations can be constructed only numerically. Traditionally the construction of the approximated analytical solutions of contact problems for thin coatings, thick coatings as well as for the coatings, comparable on a thickness with the sizes of a stamp, requires the application of various methods (a regular asymptotic method, singular asymptotic method, methods of orthogonal multinomials, collocations, etc.). Each of the applied methods is effective in its own area of values of characteristic geometrical parameter of a problem.

The given work develops the approximated analytical method of the solution of the dual integral equations, generated by contact problems of the elasticity theory for inhomogeneous coatings. We suggest the new effective method of construction of analytical approximations of kernels’ transforms of the dual integral equations of contact problems for inhomogeneous environments by the functions of a special kind. On the basis of transforms’ approximation of high accuracy, analytical solutions of contact problems for materials with coatings of complicated structure are constructed. The method is dual-sided asymptotically exact and it allows receiving in the uniform analytical form the approximated solution of contact problems, effective for coatings of any thickness.

There have been considered problems for the elastic environment with an inhomogeneous coating of periodic structure for which the gradient of change of elastic properties repeatedly changes a sign (up to 50 times). Nonmonotonic verification of elastic properties in a coating, connected with a sign-variable gradient of change of elastic properties, makes essential impact on properties kernels’ transforms of these integral equations. There are constructed the approximated analytical solutions of contact problems for the materials with an inhomogeneous coatings at which the rigidity of a substrate many times exceeds the rigidity of a coating (up to 1000 times). Such model corresponds to a model of the basis in the form of an inhomogeneous layer on a nondeformable substrate. The estimation of an error of the constructed approximated analytical solutions is made, which is important for appendices. We have investigated the influence of the structure of the functionally-gradient coatings on a distribution of contact stresses acting under a stamp, as well as the influence on the stresses fields, deformations and displacement inside the elastic basis.

Work is executed with financial support of grants of the RFBR №11-08-91168-GFEN_a, AVCP 2.1.2/10063, GK №11.519.11.3015, 11.519.11.3028.
TIME-HARMONIC LAMB’S PROBLEM FOR A SYSTEM CONSISTING OF AN IMPERFECTLY-CONTACTED ORTHOTROPIC COVERING LAYER AND AN ORTHOTROPIC HALF-PLANE

S. D. Akbarov¹² and N. İlhan³

¹Yildiz Technical University, Faculty of Mechanical Engineering, Department of Mechanical Engineering, Yildiz Campus, 34349 Besiktas, Istanbul-Turkey;
²Inst. of Mathematics and Mechanics of the National Academy of Sciences of Azerbaijan, 370141, Baku, Azerbaijan;
³Yildiz Technical University, Faculty of Civil Engineering, Department of Civil Engineering, Davutpasa Campus, 34220 Esenler, Istanbul-Turkey.

akbarov@yildiz.edu.tr, ilhan@yildiz.edu.tr

In this paper, within the framework of the piecewise homogeneous body model with the use of the exact equations of the linear theory of elastic waves time-harmonic Lamb’s problem for the system consisting of imperfectly contacted orthotropic covering layer and orthotropic half-plane is studied. In this case the investigation of the considered problem is based on the following field equations

\[
\frac{\partial \sigma_{ij}^{(m)}}{\partial x_i} = \rho^{(m)} \frac{\partial^2 u_j^{(m)}}{\partial t^2},
\]

\[
\sigma_{ij}^{(m)} = A_{ij}^{(m)} \varepsilon_{ij}^{(m)}, \quad \sigma_{ij}^{(m)} = 2G_{ij}^{(m)} \varepsilon_{ij}^{(m)} \quad \text{for } i \neq j, \quad \varepsilon_{ij}^{(m)} = \frac{1}{2} \left( \frac{\partial u_i^{(m)}}{\partial x_j} + \frac{\partial u_j^{(m)}}{\partial x_i} \right). \tag{1}
\]

In Eq. (1) the conventional notation is used. It is assumed that the covering layer occupies the region \(-\infty < x_1 < \infty, \quad -h \leq x_2 \leq 0, \quad -\infty < x_3 < +\infty\), but the half-plane occupies the region \(-\infty < x_1 < +\infty, \quad -\infty \leq x_2 \leq -h, \quad -\infty < x_3 < \infty\).

The plane-strain state is considered. The following boundary and contact conditions are satisfied

\[
\sigma_{12}^{(1)} \bigg|_{x_2=0} = 0, \quad \sigma_{12}^{(1)} \bigg|_{x_2=0} = P e^{jwt}
\]

\[
\sigma_{12}^{(2)} \bigg|_{x_2=-h} = \sigma_{12}^{(1)} \bigg|_{x_2=-h}, \quad u_2^{(1)} \bigg|_{x_2=-h} = u_2^{(2)} \bigg|_{x_2=-h}, \quad u_1^{(1)} \bigg|_{x_2=-h} = u_1^{(2)} \bigg|_{x_2=-h} = \frac{F}{\mu_{12}^{(1)}} \sigma_{12}^{(1)} \bigg|_{x_2=-h}. \tag{2}
\]

Problem (1)–(2) is solved by employing the method developed in [1] and the numerical result for stress distribution on the influence of the mechanical properties of the system and imperfect contact condition are presented and discussed.

REFERENCE

Akbarov S. D. and İlhan N. ‘Time-harmonic dynamical stress field in a system comprising a pre-stressed orthotropic layer and pre-stressed orthotropic half-plane”, Archive of Applied Mechanics, 80, 1271–1286, 2010.
INFLUENCE OF THE INITIAL STRAINS OF FACE LAYERS ON THE TORSIONAL WAVE PROPAGATION IN A HOLLOW SANDWICH CYLINDER (SOFT CORE AND STIFF FACE LAYERS)

S. D. Akbarov¹, T. Kepceler¹, and M. M. Egilmez¹

¹Yildiz Technical University, Faculty of Mechanical Engineering, Department of Mechanical Engineering, Yildiz Campus, 34349, Beşiktas, Istanbul-Turkey,
²Institute of Mathematics and Mechanics of the National Academy of Science of Azerbaijan, 37041, Baku, Azerbaijan
e-mails: akbarov@yildiz.edu.tr; kepceler@yildiz.edu.tr; megilmez@yildiz.edu.tr

Within the scope of the piecewise homogeneous body model with the use of the Three-dimensional Linearized Theory of Elastic Waves in pre-strained bodies the torsional wave propagation in a sandwich hollow cylinder with initially strained face layers is studied. It is assumed that the material of the face layers is more rigid than that of the core layer. Elasticity relations for these material are given through the harmonic potential. Initial strains correspond to the stretching or compressing of the face layers of the cylinder in the lying direction of that. Dispersion equation is derived and as a result of the asymptotic analysis of this equation the analytical expression is obtained for the limit values of the wave propagation velocity under low wave number. Moreover, numerical results on the influence of the initial strains of the face layers of the cylinder on the dispersion curves are presented and discussed. In particular, it is established that the initial stretching (compressing) of the face layers causes to increase (to decrease) of the torsional wave propagation velocity.
BUCKLING DELAMINATION OF ELASTIC AND VISCOELASTIC COMPOSITE PLATES WITH CRACKS

S. D. Akbarov

Yildiz Technical University, Faculty of Mechanical Engineering, Department of Mechanical Engineering, Yildiz Campus, 34349, Besiktas, Istanbul-Turkey
e-mail address: akbarov@yildiz.edu.tr


The present paper deals with detail review-analyses of the results related to buckling delamination of the elastic and viscoelastic plates. These results have been obtained during the last fifteen years by the author and his students. Both the continuum and piecewise homogeneous body models have been employed for describing of plate materials. It was assumed that the plates contain cracks the edges of which have initial infinitesimal imperfections. Cracks’ location so it is under absent the mentioned imperfection cracks’ edges are parallel to the free face planes of a plate. Within these assumptions, the evolution of the initial infinitesimal imperfection is studied under compression of the plate. This study is performed with the use of the three-dimensional geometrically non-linear equations of the theory viscoelasticity for anisotropic (orthotropic) bodies. The results related to plane-strain state, axi-symmetric and three-dimensional buckling delamination problems are presented and discussed. The initial imperfection criterion is used for the determination of the values of the critical parameters. For solution of the corresponding non-linear boundary value problems the boundary form perturbation technique, Laplace transformation with respect to time and FEM are employed. For describing of the viscoelasticity of the plate materials, the fractional-exponential operator by Rabotnov is used.
Mechanics of Composite Materials - 2012

3D FEM ANALYSIS OF STRESS CONCENTRATIONS AROUND TWO NEIGHBORING CYLINDRICAL HOLES WITHIN A PRESTRESSED RECTANGULAR COMPOSITE PLATE UNDER BENDING

S. D. Akbarov\textsuperscript{1,2}, N. Yahnioglu\textsuperscript{3}, and U. Babuscu Yesil\textsuperscript{3}

\textsuperscript{1}Yildiz Technical University, Faculty of Mechanical Engineering, Department of Mechanical Engineering, Istanbul, Turkey

\textsuperscript{2}Institute of Mathematics and Mechanics of Azerbaijan National Academy of Sciences, Baku, Azerbaijan

\textsuperscript{3}Yildiz Technical University, Faculty of Chemical and Metallurgical Engineering, Department of Mathematical Engineering, Istanbul, Turkey

This paper studies the influence of the initial stresses on the stress concentration around two neighboring cylindrical holes within an orthotropic rectangular plate. The considered plate is simply supported at all the edge-sides and the two neighboring cylindrical holes are placed inside of the plate and lie width-wise horizontally. It is supposed that in the initial state the plate is loaded by uniformly distributed stretching or compressing normal forces acting on the opposite two end planes which are parallel to the longest axis of the holes. Also, assume that the additional uniformly distributed normal forces act on the upper free-plane of the considered plate. It is required to determine how the initial stress state affects on the stress concentration caused by the additional forces noted above. The corresponding problem is formulated in the framework of the three dimensional linearized theory of elasticity. This mathematical modeling is solved in two stages. In the first stage, the initial stress distribution caused by the normal forces acting on the opposite two end surfaces are determined by utilizing the classical linear theory of elasticity for an anisotropic body. In the second stage, the influence of the initial stresses determined in Stage 1 on the stress concentration caused by the additional forces is studied by utilizing the three dimensional linearized theory of elasticity. This mathematical modeling is solved in two stages. In the first stage, the initial stress distribution caused by the normal forces acting on the opposite two end surfaces are determined by utilizing the classical linear theory of elasticity for an anisotropic body. In the second stage, the influence of the initial stresses determined in Stage 1 on the stress concentration caused by the additional forces is studied by utilizing the three dimensional linearized theory of elasticity. In paper [1], the influence of an interaction between two neighboring circular holes in a pre-stressed orthotropic strip under bending was studied in the plane strain state. In the present paper the investigation [1] is developed for the case where the strip contains two neighbouring cylindrical holes for the rectangular composite plate, i.e. omitting the assumption of the plane strain state. The considered problems of the both stages are solved numerically using 3D Finite Element Method (FEM). The influence of the material and geometrical parameters and interaction between the holes as well as the initial stresses on the concentration of stresses around the cylindrical holes are presented and discussed.

REFERENCES

3D FEM ANALYSIS OF THE BUCKLING DELAMINATION OF A RECTANGULAR PLATE WITH AN INNER RECTANGULAR CRACK UNDER BIAXIAL COMPRESSION FORCE

S. D. Akbarov¹,², N. Yahnioglu³, and E. E. Karatas⁴

¹Yildiz Technical University, Faculty of Mechanical Engineering, Department of Mechanical Engineering, Yildiz Campus, Istanbul, Turkey
³Yildiz Technical University, Faculty of Chemical and Metallurgical Engineering, Department of Mathematical Engineering, Davutpasa Campus, Istanbul, Turkey
⁴Yildiz Technical University, Faculty of Civil Engineering, Department of Civil Engineering, Davutpasa Campus, Istanbul, Turkey

In this study, the investigation of Akbarov et al. [1] is extended for a buckling delamination problem of a rectangular composite plate with a rectangular inner-interface crack, subjected to bi-axial compressive force. It is assumed that the considered plate is simply supported at all the edge surfaces of the plate, on which the uniformly distributed compressive forces act. It is also supposed that the crack edge-surface has an initial infinitesimal imperfection before the loading of the plate.

The evolution of this initial imperfection is studied in the framework of the three-dimensional geometrically nonlinear field equations of the theory of elasticity for anisotropic bodies. For the determination of the values of the critical buckling delamination force as well as the buckling determination mode of the considered plate, the initial imperfection criterion is used.

For the solution to the corresponding boundary-value problems the boundary form perturbation technique and the 3D FEM are employed. The influence of the materials and geometrical parameters of the plate and of the crack on the critical values is present and discussed.

REFERENCES

BUCKLING DELAMINATION OF A RECTANGULAR SANDWICH PLATE CONTAINING INNER CRACKS UNDER BI-AXIAL LOADING

S. D. Akbarov¹, N. Yahnioglu², and A. Tekin³

¹Yildiz Technical University, Faculty of Mechanical Engineering, Dept. of Mechanical Engineering, Yildiz Campus, 34349, Besiktas, Istanbul, Turkey
²Yildiz Technical University, Faculty of Chemical and Metallurgical Engineering, Dept. of Mathematical Engineering, Davutpasa Campus, 34210, Esenler, Istanbul, Turkey
³Yildiz Technical University, Faculty of Civil Engineering, Dept. of Civil Engineering, Davutpasa Campus, 34210, Esenler, Istanbul, Turkey

In this study, the investigation considered in [1] is developed for the buckling delamination problem of an elastic sandwich plate containing two same parallel inner interface cracks under bi-axial loading. Face and core layers’ materials are isotropic and homogeneous, and elasticity modulus of the core layer is greater than that of the face layers. It is also assumed that before the plate loading the edge-surfaces of the cracks have initial infinitesimal imperfections. Due to bi-axial external compressive loading of the sandwich plate these initial imperfections of the edge surfaces of the cracks start to increase. Hence, the region bounded by edge surfaces of the cracks and the face layer are liable to local buckling delamination under these compressive loads, thereby creating conditions conducive to delamination growth and consequent global failure of the structure. Therefore, the investigation of the considered buckling delamination problem is reduced to analyze of the evolution of the mentioned imperfections of the crack-edge surfaces. The mathematical modeling of the corresponding problems is formulated within the framework of the piecewise homogeneous body model with the use of the three dimensional geometrically nonlinear exact equations of the theory of elasticity. For the determination of the values of the critical buckling delamination force, the initial imperfection criterion is used. For the solution of the considered problems, boundary form perturbation techniques and the three-dimensional finite elements method (FEM) are used. The numerical results related to the influence of some geometrical and material parameters of the plate on the critical buckling delamination force and modes are presented and discussed.

REFERENCES

CALCULATIONS OF FIBER-REINFORCED RIGID CYLINDERS UNDER THE INFLUENCE OF CENTRIFUGAL FORCES AND THE FRAME THEORY

V. M. Akhundov and T. A. Skripochka
The National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine

The calculations of plane strain deformation of composite cylinders with high volume content of fibers under the influence of centrifugal forces are performed. Thick cylinders made of epoxy matrix reinforced with one, two and three systems of fibers in the axial, radial and district lines. The cylinders with free and hard landing and rotation speeds that determine small elastic deformations of the matrix and fibers frame theory [2], as well as the theory of effective modules [3].

In general, applied theory is designed to analyze low reinforced fiber bodies. Framing theory doesn’t impose restrictions on the fiber content in the bodies. Macromechanical level analysis of the theory is based on the locally-structural level, in which are determined by the internal fields from nodal block to represent the structure of the model using a piecewise-homogeneous body. The comparing the results obtained with applied and framing theories enables to identify the opportunities of applied theory. The results of the calculations involved of the theory of effective modules for additional validation calculations on applied and framing theories of rigid fibrous bodies at small strains.

The result was demonstrated the high accuracy of the theory of frame analysis macromechanical hard fibrous bodies at small strains on the basis of the definition of internal fields. It was confirmed that the applied theory adequately reflects the behavior of fibrous bodies with high fiber and filling at small strains, if they are oriented in the past on power fields.

REFERENCES

INCREMENTAL FRAME THEORY OF FIBROUS MEDIA UNDER LARGE ELASTIC, CREEP AND PLASTIC DEFORMATIONS

V. M. Akhundov

The National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine

Two-level skeleton theory, which constructed in [1, 2], extended to medium fiber structure under small and large elastic, creep and plastic deformation of the matrix and fiber material. The decision on the micromechanical level boundary (mikromarginal) problems for nodal blocks representiv the structure of the material medium is carried out on the base incremental theory which based on the mapping of irreversible deformation of the material components depending on the total strain [3]. The state of stress is seen as conditional on the transformation of irreversibly deformed configuration of the components of the material in completely deformed configuration. Problem of large elastic deformations of the material medium in the presence of large irreversible strain gets completely clear solution.

At the makromehanical level of analysis are formed geometric equations of macroscopic deformation and the macroscopic equations of motion in incremental form, reflecting the incremental approach used in the micromechanical level of analysis. The boundary conditions of mikromarginal problems for nodal block material are determined on the base of calculated on makromehanical level components of macroscopic deformation. Solving these problems on the base of the model of piecewise-homogeneous body identify incremental increments padding protection for incremental steps in the history of loading. Subsequent determination of incremental macroscopic stress increments in the nodal locations of blocks found on the basis of the internal fields and their incremental increments can close the system of equations makromehanical level. The fields of incremental macroscopic displacements, strains and stresses, and the resulting macroscopic field of the medium on the incremental step of loading determined by the solution of boundary value problem makromehanical level. The following step of the iteration procedure and refinement of internal macroscopic field medium run next.

As a result, by the solution of the mechanics of deformation of the fiber of medium small and large deformations elastoviscoplastic material components, taking into account the history of deformation of the material and the whole of the medium. It is possible to forecast the destruction of the matrix and fibers and the interface between them due to the presence of a micromechanical level of analysis. The possibility of accounting and internal loss of stability when the local curvature of the fibers are in the matrix material of the medium also is important.

REFERENCES

METHOD OF FRAME BLOCKS IN THE MECHANICS OF COMPOSITE MATERIALS AT HIGH GRADIENTS OF STATE

V. M. Akhundov

The National Metallurgical Academy of Ukraine, Dnepropetrovsk, Ukraine

Method of computational mechanics of composite media with high gradients of the states with small and large deformations of the material components of medium – a method of frame blocks (MFB) – is proposed. The method has two levels of analysis, based on the separation of the two systems (sets) of the material points of the medium. Macromehanical (upper, first) level of analysis is based on the separation of a composite medium in blocks which called “frame”, and the introduction of the corresponding set of skeletal points. The tops of the blocks that are shared by the composite medium are taken on as a frame of points. The skeletal points serve as macropoints – sampling points of the upper level of analysis. The (frame) blocks of the medium are sampling on micromechanical (bottom, second) level of analysis. The set of points is a frame with a subset of micropoints – nodal points sampling of the lower level of analysis. Accordingly, the systems of macro- and micropoints are introduced into consideration frame field (macroscopic) and material (internal) displacements, which define the position of the corresponding sets of points in the current configuration of the medium. The field of frame displacement has a key role and methodologically it is primary, and the field of material displacement, as a derivative of the field frame displacement – secondary. Macroscopic concepts (skeleton) deformation and stress in this approach, in contrast to the corresponding concepts in the frame of the theory of smooth (low) gradients of state [1, 2], are irrelevant. The basic concepts of macromehanical level of analysis, in addition to skeletal movementsis, are the concept of neighborhood effects and the concept of framing the point of total energy (static loading) or action (dynamic loading) environment blocks that make up the neighborhood influence skeletal point. Macroscopic and material displacement field (the first and second levels) are determined in high states of the medium gradients on the basis of differential or extreme formulations of static or dynamic tasks of the research medium. Application of two-tiered approach allows one the effective implementation of medium analysis at high gradients of the state, including the conditions of internal instability and the manifestations of regional and marginal effects. Irreversible deformation of the material components of the medium approach is implemented in an incremental form, which allows to take into account the history of deformation of the components of the material [3].

REFERENCES

ELASTIC AND DISSIPATIVE MATERIAL PROPERTIES OF ALLUMINIUM ALLOYS WITH CARBON NANOTUBES

P. Akishin, E. Barkanov, R. Smyth, and T. McNally

1Institute of Materials and Structures, Riga Technical University Kalku St. 1, LV-1658, Riga, Latvia
2School of Mechanical and Aerospace Engineering, Queen’s University Belfast BT9 5AH, Belfast, UK

Carbon nanotubes (CNTs) and their mechanical properties have been investigated since the early 1990s. The main research was focused on using of CNTs to reinforce polymer and ceramic matrices but the interest in metallic-CNT composites has grown considerably in the last decade. Of particular interest is CNT-reinforced aluminium alloys which have promising potential for application in many industrial sectors such as aerospace, automotive and electronics.

Composites were made by adding CNT’s to molten aluminium alloy via gravity casting into a mould. Ten nanocomposite billets were prepared using this technology: two billets of pure aluminium alloy LM24 and two billets of the same alloy with different CNT volume content of 0.1, 0.3, 0.5 and 1.0%. Then two types of specimens: beams with the dimensions of 80mm or 70mm or 60×10×2 mm and plates with the dimensions 80×60×2 mm were machined from these billets for experimental investigations. It is necessary to note that specimens were taken from 5 different positions from a large billet to study a variation of material properties as a function of billet thickness.

Different nondestructive techniques for the elastic and dissipative material property characterisation were developed and adapted for the testing of nanocomposite specimens with small geometrical dimensions. Static approach using a three-point-bending test and two dynamic methods, namely, impulse excitation method and inverse technique based on vibration tests and using the planning of experiments and response surface methodology were applied for the determination of the elastic properties of these materials. The dissipative material properties were characterised by a structural loss factor obtained by the peak-picking method analysing the frequency response functions of specimens in the points of resonance.

The addition of CNTs to the aluminium alloys did not yield a visible increase in their elastic properties. However, instability in elastic properties through the thickness of billet was observed. This could be explained by a gradient of CNTs distribution due to the limitations of the gravity casting process.

The experimental results show that addition of CNTs to this aluminium alloy decreases their dissipative material properties for bending and twisting modes. If for bending modes the maximal average deviation (in comparison with pure aluminium alloy) is 32%, for twisting modes the maximum average deviation was 45%. It is necessary to note that material investigated did contain pores. Unfortunately, pores have considerable influence on the dissipative material properties therefore it was not possible to obtain a clear dependence of the material loss factors on frequency for the specimens with different CNT volume content in a wide frequency range.

The problem of a gradient of CNT distribution throughout the aluminium alloy and porosity of material could be probably overcome producing CNT-reinforced aluminium alloys using die casting.
Fiber-reinforced polymer matrix composites (PMCs) are growing in popularity as a replacement to conventional materials in civil infrastructure, constructions, and marine applications. The manufacture of large-scale profiles of PMCs with various cross-section shapes for weight-critical structures became potentially possible with application of the pultrusion method. PMCs change their service properties at high temperatures. Thus, a critical aspect of using the PMCs is their performance in high temperature environment. The kinetics of heat diffusion into pultruded profile depends on the structure of PMC: properties of the constituents, their relative content and layer sequence, as well as geometry of the profile itself.

Commercial finite element code ANSYS 11.0 was used for numerical 2D modelling of transient thermal process for an orthotropic I-beam cross-section.

The main objective of the research is to estimate the error, concerned with the model simplification assumed for an analytical solution of the problem. The main idea of this simplification is virtual splitting of I-beam cross-section into three simple elements (two flanges and web plates). This simplification excludes accounting for the internal thermal flux between these components of the I-beam. The dimensions of flanges and web are 100 × 20 cm; density of the I-beam material \( \rho = 1000 \, \text{kg/m}^3 \), specific heat capacity \( c = 1000 \, \text{J/(kg\times K)} \), heat conductivity across fibres of material \( K_y = 10 \, \text{W/(m\times K)} \). The range of values of heat conductivity along fibres from 5 to 100 W/(m×K) is considered. Thus, the heat conductivity ratio varies in the range from 2:1 till 1:10.

Three computational models were evaluated and compared in this research. In the first case, the I-beam cross-section is modelled as a whole unit; the temperature load was applied to all external borders of the section. This model allows us to evaluate the intensity of the heat flux between the elements of the cross-section and, consequently, the total amount of heat involved in this heat transfer. It is determined by varying of heat conductivity ratio from 2:1 to 1:10 that the ratio of heat flowed from the flanges to the web at the end of transient process to the total quantity of heat taken up by the cross-section varies according to logarithmic law from -0.7 to 2.6%.

The second model corresponds to the first in the loading scheme, but the flanges and the web are considered as independent elements. Comparison of the results obtained showed no significant effect of this simplification on the dependences of mean temperatures of cross-section elements on the time of transient process.

The third model differs from the previous ones by thermal loading scheme. The thermal load is applied to all external faces of the flange without break at the place of its adjunction with the web. This model was chosen because it corresponds to the model applied for appropriate analytical solution. This allows us to verify the finite element model and use results of numerical experiments in analytical calculations. It is stated that the error of this simplification increases by decreasing of heat conductivity along fibres.

Our research allows concluding that the model simplification has not significant effect on the kinetics of transient thermal process. The maximum difference of the flange averaged temperature in the transient process is 6% for the heat conductivity ratio 2:1, and 2% for the heat conductivity ratio 1:10. Thus, this simplification of the model is valid for the approximate engineering methods of calculation.
ANALYSIS OF DELAMINATION IN LAMINATED COMPOSITE MATERIALS FOR HORIZONTAL-AXIS WIND TURBINE BLADE APPLICATION

O. Al-Khudairi, H. Hadavinia, B. Osborne and E. Lewis

School of Mechanical and Automotive Engineering, SEC Faculty, Kingston University, London, UK

In engineering applications, material selection is very important as most components need to be light and rigid to withstand various loads. For example in horizontal axis wind turbines (HAWT), the blade acts as a long cantilever beam, of the order of 160m, so selecting a material that does not cause the structure to fail under its own load and operating load is very important. Glass Fibre Reinforced Polymer (GFRP) is a laminated composite material which is commonly used today for high strength and low weight blade design. Laminated Fibre Reinforced Polymer (FRP) composites, however, are prone to delamination as a result of transverse stresses, impact loading and manufacturing defects. To assist in better designing future composite blades or understanding the performance of current designs it is crucial to calculate the damage tolerance of the composite structures. In order to correctly evaluate the stability of damage under load, appropriate mechanical properties must be accurately obtained.

In composite materials there are three modes of fracture that occur; mode I is when the crack is opening under tensile stresses, mode II happens under shearing load and mode III is when the material faces a tearing load. In most practical applications, the structure will withstand a mixed mode I/II loading. Hence, characterization of laminated composite under these modes and mixed mode loading are important. Three different experiments are used to measure the fracture toughness; i.e. mode I- Double Cantilever Beam (DCB) test, mode II- End Notch flexure (ENF) test and mixed mode I/II- Mixed Mode Bending (MMB) test. In this paper the failure envelope for laminated GFRP has been obtained under mixed mode loading.
SOME EFFECTS OF VISCOELASTICITY ON THE ABILITY TO MODEL
FAILURE IN COMPOSITES

D. H. Allen
University of Texas-Pan American, Edinburg, TX 78539, USA.

The classical approach to modeling the thermomechanical response of composites employs a framework embodied within the concept of continuum mechanics. This approach may not always lead to success in that some failure mechanisms such as molecular scale phenomena may not be accurately captured by the continuum approximation. On the other hand, the continuum approach may be quite powerful and accurate for predicting failure in a variety of circumstances. For any continuum mechanics based approach to have hope of accuracy it is, however, necessary for that model to in some sense capture the physics of all of the cogent energy dissipative processes that are engendered in the actual application. One part of the traditional continuum mechanics approach that is often misused toward this end is in the deployment of a constitutive model. Careful consideration of thermodynamics will lead to the conclusion that elastic materials cannot dissipate energy. Nonetheless, it is quite commonplace to see a linear elastic analysis utilized to predict failure of a structure. Sometimes this approach may turn out to be accurate despite the clear contradictory nature of the framework, but in many other cases the approach may be fatally flawed from the outset. In the latter case, it is sometimes possible to introduce sufficient improvement in a continuum based model by incorporating a viscoelastic constitutive model that the model is capable of making substantially improved predictions of failure.

The current paper is concerned with delineating via a series of example problems circumstances wherein the inclusion of viscoelasticity into the constitutive model deployed in a continuum mechanics framework has proven to be at least somewhat successful, thus obviating the necessity for employing what may be even more complicated still in the pursuit of "an accurate yet simple model", to paraphrase Isaac Newton.

It will be shown that a judicious deployment of viscoelasticity in the bulk material can dramatically improve predictions of failure due to fracture both in impact problems and in cyclic fatigue problems. It will also be shown that accounting for viscoelasticity in a fracture model can further enhance the predictive capability due to the fact that the inclusion of both of these effects produces dissipation that accounts in a phenomenological way for physically important energy loss mechanisms that are known to contribute to failure.
DESIGN AND TESTING OF SANDWICH PANELS FOR TRAILERS

G. Allikas¹, A. Aruniit¹, H. Herranen², H. Lend², J. Majak², M. Pohlak², and O. Pabut²

¹Tallinn University of Technology, Dep. of Materials Engineering, EST-19086, Tallinn, Estonia
²Tallinn University of Technology, Dep. of Machinery, EST-19086, Tallinn, Estonia

Sandwich composites consist of a thick core and thin facesheets, sandwich panels achieve considerably high shear-stiffness-to-weight ratios and bending-stiffness-to-weight ratios than equivalent homogeneous plates made exclusively of the core material or the facesheet material. The primary factors that influence the structural response of a sandwich panel are laminate thickness, core thickness and core density [1].

The aim of the current study was to design and test sandwich panels to achieve maximum mechanical properties with lowest cost. The sandwich test specimens were made using vacuum infusion process (VIP). The different types of sandwich specimens were tested in 4-point bending mode according to standard ASTM C393/C393M. The gained data was used to build up 3D sandwich panel model for finite element analysis (FEA) which was made with ANSYS software. The static analysis was made to evaluate different layers stresses and the whole panel deformation. The potential laminate failure was analysed using Tsai-Wu failure criteria and the core failure was analysed using shear stresses. The modal analysis was performed to evaluate dynamic loads existing in trailers while car is driving. Based on FEA results the Pareto optimality concept has been employed and optimal solutions are determined by applying multi-criteria analysis techniques and genetic algorithms [2].

The main results obtained can be outlined as:
- based on experimental study and FEA the procedure for design of the light-weight sandwich panel with advanced mechanical properties and low cost is developed;
- proceeding from on artificial neural network (ANN) model treated, the closed form analytical expressions are derived for computing the sensitivities with respect to design variables;
- the design appears more sensitive with respect to sandwich core material selection than laminate thickness (the total thickness of the sandwich panel remained same);
- the sensitivity of the solution with respect to design variables is times higher in points neighbouring the discontinuity points of the Pareto front (critical points).

REFERENCES

ANALYTICAL MODEL TO PREDICT THE SHEAR CAPACITY OF REPAIRED DEFICIENT REINFORCED CONCRETE BEAMS DAMAGED BY SULFATE USING COMPOSITE MATERIALS

R. Alrousan and R. Haddad

Dept. of Civil Engineering, Jordan University of Science and Technology, Irbid, Jordan

In spite of shear behavior of an RC beam is more difficult and complicated to understand than its bending behavior, recent experimental researches on the strengthening of shear deficient RC beams using FRP Composites have confirmed the feasibility of this technique. On the other hand, there is a limitation on the using of the existing analytical proposed models to predict the shear capacity of undamaged strengthened RC beams. In this paper, a challenge is made to develop a suitable model concerning the structural behavior of damaged RC beams by sulfate strengthened to enhance shear resistance taking into account the behavior of the interface bonded area between concrete and the composite materials. The advantages of this proposed model is considering the failure modes which influenced by bond slip, specifically, the debonding phenomenon. The model has been validated against a large number of tests representing a wide range of structural variables and test geometries and reported from different sources. The results show that the proposed can predict the test results constantly and acceptably with a coefficient of variation of approximately less than 15%. Finally, the proposed model is then compared with the other existing models, and it is revealed that the proposed model gives a clear picture for the test data with much better correlation than the other existing models.
ENVIRONMENT EFFECT ON THE PULSATING FLOW OF A LIQUID IN A MULTILAYER VISCOELASTIC PIPE


Baku State University, 23, Z.Chalilov st., Az-1148 Baku, Azerbaijan, mexanika.bsu.az@mail.ru

In the report, pulsating flow of liquid enclosed in a deformable pipe is considered on the base of linear averaged one-dimensional equations, with regard to environment effect.

The mathematical model of the system used here is described by the equation of motion of ideal incompressible liquid combined with continuity equation and dynamical equation for a constant cross section multilayer viscous elastic pipe. It is assumed that the pipe is made of the $n$ layers alternating in thickness and related between themselves by general concentric surfaces. Assuming that division of layers is symmetric with respect to median surface, the momentless theory is taken as a base. Rigid adhesion is the contact condition between the layers of the packs. It is accepted that the stress on the wall is modelled under the assumption that the environment introduces additional lag, rigidity and damping.

For describing pressure, liquid discharge and displacements in the case of finite length pipe, the pressure is given on its end faces. The solution for a semi-infinite pipe is obtained by a limit transition. Qualitatively, physical-mechanical and geometric parameters effect on wave characteristics is revealed for the case of no external bonds for a three-layer pipe with periodic structure.

In particular it was established that the wave propagation speed may be decreased (increased) by “designing” the inhomogenity.
A NOVEL ECOLOGICAL HEAT-INSULATING COMPOSITE OF A STEAM-EXPLODED BIOMASS

M. Andzs¹, J. Gravitis², and J. Abolins³

¹Latvia University of Agriculture, Forest faculty, Dep. of Wood Processing, Jelgava, LV-3001, Latvia
²Laboratory of Biomass Eco – Efficient Conversion, Latvian State Institute of Wood Chemistry, 27 Dzerbenes Str, Riga, LV-1006, Latvia
³Institute of Atomic Physics and Spectroscopy, University of Latvia, 19 Rainis Blvd., Riga, LV-1586, Latvia

Hemp (Cannabis sativa), an agricultural crop mainly cultivated to obtain fibre, lately is finding use as a source for diverse construction materials of shears of the hemp bark left as production residues after extraction of the fine fibres. However, utilisation of the shears in constructions composites together with various chemicals to achieve the desired physical properties of the product often reduces the factors determining its environmental qualities such as absence of health hazards during exploitation and toxic emissions at recycling particularly important in applications for heat insulation of living houses and working space.

The work presented is a study of the effect of steam explosion treatment on the properties of hemp shears essential for application as heat insulating composites friendly to environment and humans.

Steam explosion auto-hydrolysis (also referred to as steam explosion pulping, flash auto-hydrolysis, or steam cracking) is a simple treatment of biomass (agricultural waste, logging residues, municipal waste, etc.) by saturated steam, usually at pressures up to 40 atmospheres. The treatment time varies from some seconds to several minutes after which time the biomass is instantly decompressed (exploded) to ambient pressure. The obtained mass comprising microscopic fibrous particles of the fragmented hard parts of the bark is proper ecological composite filler without chemical contaminants usable in roof, partitions, and floors of buildings. SE biomass (wood chips, straw, hemp shreds, etc.) being excellent absorber of air moisture is a favourable component in building constructions.

The first results of a comprehensive original study of the effects of SE treatment: mass recovery after the treatment, size fractions of the steam-exploded material, bulk and loose density, thermal conductivity and effects of particle size on thermal conductivity of the filler, and modelling of life cycle assessment are reported.
LINEAR VISCOELASTIC APPROACH TO THE TENSILE CREEP OF EPOXY RESIN WITH A VARIABLE MOISTURE CONTENT

A. N. Aniskevich	extsuperscript{1}, R. M. Guedes	extsuperscript{2}, and O. Starkova	extsuperscript{1}

	extsuperscript{1}Institute of Polymer Mechanics, University of Latvia, 23 Aizkraukles str., Riga, LV-1006, Latvia, e-mail: andrey@pmi.lv

	extsuperscript{2}Department of Mechanical Engineering and Industrial Management, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias s/n, 4200-465 Porto, Portugal e-mail: rmguedes@fe.up.pt

Polymer composite constructions during their service life undergo creep under the action of variable environmental conditions, humid air in particular. Relative humidity of ambient atmosphere follows daytime and season changes. Taking into account large dimensions of constructions and slow rate of moisture absorption by most of polymer binders, nonequilibrium distribution of moisture in cross section of materials is observed that, in turn, leads to swelling stresses. Epoxy resins are widely used as a matrix in composites and often determine their environmental resistance in a great extent. The objective of the study was to simulate stress-strain behaviour of a material with variable moisture content under tensile creep within a linear viscoelastic approach.

As a model material, epoxy resin was considered and all parameters of the model were taken from a set of experimental data obtained under stationary humid environment. Moisture sorption by the resin in periodically changing atmosphere was calculated using 1D analytical solution of Fick’s law. Linear viscoelastic behaviour was described by a hereditary integral with an exponential creep kernel. Moisture influence is taken into account by the Time-Moisture Superposition Principle. Based on the experimental data, a linear dependence of the swelling strain and moisture content of the epoxy resin was considered.

Viscoelastic strain-stress analysis was performed with algorithm and software LAMFLU. The specimens (thin plates) were discretized into several layers, forming a multilayer system. Stress fields were calculated for the system in different time instants corresponding to moisture concentration of the layers. General strain of a specimen was also calculated step by step summing its increment. Step- and sine-wise changes of humid environment were simulated. Analytical strain calculation was made using well known time modification principle. Time scale was modified according to specimen average moisture concentration. Variable moisture content is taken into account by means of integration along all process history. The analytical strain calculation is compared with the numerical one.
MECHANICAL PROPERTIES OF A LAYERED GLASS-FIBER-REINFORCED PLASTIC AFTER A FREEZE-THAW CYCLING

K. K. Aniskevich, V. P. Korkhov, and E. A. Faitelsone

Institute of Polymer Mechanics, Latvian University, Aizkraukles 23, Riga, Latvia

Polymer matrix composites (PMCs) are growing in popularity as a replacement to conventional materials in civil infrastructure and construction due to their high specific strength and excellent corrosion resistance. However, the problem of long-term use of PMC structures remains important due to technological stresses in the structure, composing the materials with different densities, thermal and mechanical properties. The presence of unbound water in the structure, which can freeze at sub-zero temperatures, causes additional stresses. As the structures have to work in a wide temperature range, an investigation of the effect of sub-zero temperatures on the service properties of PMC is important. The experimental evaluation of mechanical properties of composite material, both dry and moistened up to saturation, during freeze-thaw cycling was the purpose of present work. The work was done at a laminate scale level of the pultruded profile, which was made of isophthalic polyester matrix reinforced by alternate layers of E-glass rovings and mats. As the design of fiber-reinforced pultruded beams is often governed by deflection limits in service, flexural properties and thermal expansion were considered.

The experimental investigation of flat coupons, cut from the flanges of pultruded I-beam, showed that:

- Freeze-thaw cycling of both dry (conditionally initial) and wet (after moistening up to saturation) material results in an increase of flexural modulus and decrease of ultimate strain and strength. The effect is more expressed for dry material.
- An improvement in the elastic modulus of the material is in line with the decrease of thermal expansion coefficient along the fiber axis.
- Linear thermal expansion coefficients (LCTEs) in three principal axes of the layered composite are different: the largest one is in transverse to fiber axis out of layers plane. The LCTEs of wet material in transverse to fiber axis are larger than of dry.
- Heating up to 125°C and subsequent cooling results in a residual (shrinking) volume strain.
- The changes of flexural characteristics, LTECs, and shirking strain after heating-cooling during freeze-thaw cycling are mediated by the change of moisture content in the material specimens.
MODELS AND METHODS FOR STRENGTH CALCULATION OF COMPOSITE MATERIALS AND CONSTRUCTIONS

A. N. Anoshkin

State National Research Polytechnical University of Perm, 29 Komsomolski Ave., Perm, 614990, Russia, anoshkin@pstu.ru

There were mechanics models considered that describe the processes of composite materials and multilayer composite structures destruction. Many composite structures are used in difficult conditions of loading, so there is high demand for weight reduction. Despite the small thickness, there are non-uniform stress and strain fields appears in the walls of structures, characterized by significant gradients. Processes of deterioration can flow in layers of the composite material, long before the end of their bearing ability. These features should be considered for composite structures rational design and their performance analysis.

The deformation of a unidirectional fiber composite material (UFCM) under different loading conditions is described by a three-phase model: matrix, fiber and an interphase layer. Matrix and interphase layer were taken isotropic and nonlinearily elastic, and fiber – elastic and transversely isotropic. The problem of calculating the structural stress and strain fields is solved by the local approximation and the finite element method on fragments of a periodic or disordered composite structure. The destruction of the matrix, fiber and interphase layer is recorded by means of appropriate strength criteria, and then in damaged areas accepted terms of complete loss of bearing ability of the material or ability to perceive only the full round compressive load. The general nonlinear problem of space loading for each piece of composite structure is splitted into two non-linear problems: generalized plane strain state and antiplane shear, which can be solved step by step together in an iterative cycle. The solution is that obtained macroscopic nonlinear deformation diagrams and surface strength of UFCM with different loading conditions.

To describe the processes of multilayer composite structures deformation is proposed to use models that include defining relations of a set of strength criteria, scalar or tensor function of accumulated damage and elastic constants reduction conditions of the material. This allows us to simulate various destruction processes of composite layers, while preserving the ability to perceive some external load under quasi-static and cyclic loading. It is assumed that the destruction by one of the criteria leads to a loss of bearing ability only if there is a certain kind of loading. The condition of complete destruction is the simultaneous satisfaction of a certain set of criteria for destruction, but even in this case, the material can maintain bearing ability under full round pressure.

The developed UFCM models allow us to describe unidirectional material layer behavior in the construction and enable us to determine the full set of nonlinear deformation characteristics and strength criteria. The models developed for multilayer composite structures allow us refined evaluation of strength and resource that is shown by the example of strength calculation of composite flanged units of aircraft engines cover.
USE OF COMPOSITE MATERIALS IN AIRCRAFT POWER PLANTS CONSTRUCTION

A. N. Anoshkin\(^1\) and M. A. Grinev\(^2\)

\(^1\)State National Research Polytechnical University of Perm, 29 Komsomolski Ave., 614990, Perm, Russia, anoshkin@psu.ru

\(^2\)Open Joint Stock Company «Aviadvigatel», 93 Komsomolski Ave., 614990, Perm, Russia grinev@avid.ru

There is composite materials usage considered in aircraft propulsion designs developed by OJSC "Aviadvigatel" Perm. Strong weight restrictions and requirements to create an effective sound proofing engine, necessitate more widespread adoption to design parts and components from composite materials. First variants of the composite materials implementation have been proposed in the early 90s for aircraft gas turbine engine PS-90, mass-produced. To introduce composites were selected the low load thin outer contour body parts, nozzle, and the reverse. Easy access for periodic visual inspection, diagnosis, repair and replacement, if necessary, provide them safe testing while operating propulsion system. Made from composite materials, body parts have up to 20-25% less mass than metal counterparts. The fundamental technology of mass production of composite parts and assemblies of the outer contour traction engines has been developed.

Molding of composite body parts is carried out by hand laying on the mandrel differently oriented layers of glass and epoxy resin binder for carbon prepregs, followed by curing in an autoclave. A technology of flanged units and parts made of composite materials manufacturing that provides additional weight reduction compared with embedded metal flange composite parts has been developed. Computational and experimental studies have shown a sufficient stock of static strength and resources of develop composite parts, and it is confirmed by current data on flying hours of composite parts in engines. Currently, composite parts are mass-produced instead of original metal counterparts for modified versions of PS-90 - PS-90A2 engines.

D30KU-154 operated in the TU-154 is the second engine in which composite parts were used. Aircraft engines required their revision to satisfy ICAO noise reduction requirements. In this case the only possible solution was to install additional sound-absorbing panels, because of existing inner contour engine restricted dimensions. In this case polymeric composite materials were the most effective panel’s embodiment.

Currently widespread use of composite materials is planned in construction of newly designed aircraft propulsion engines based on the PD-14, intended to equip the near- and medium-haul aircraft such as MS-21. New design solutions in this case are creation more than 60% of sites nacelle engine from composite materials, creation of multi-cellular sound-absorbing panels contour, making the fairing, power components, etc. It is planned to use new processes while creating new composite engine components such as RTM, infusion, automatic layout. Introduction of composite materials should ensure engine weight reduction to perform required environmental standards.
PREDICTION OF THE EFFECTIVE ELASTIC PROPERTIES OF A SOUND-ABSORBING CIRCUIT’S FILLER OF AIRCRAFT ENGINES

A. N. Anoshkin, V. Yu. Zuyko, and E. N. Shustova

State National Research Polytechnical University of Perm, 29, Komsomolski Ave., Perm, 614990, Russia, anoshkin@pstu.ru

The fibrous polymeric composite materials (PCM) are increasingly used in manufacture of aircraft engines parts and components.

A promising direction is the usage of PCM in manufacture of sound-absorbing circuit parts. There are "resonant Helmholtz cells" of various forms between outer and inner layer of shell, and inner cladding layers are perforated.

"Resonance cells" (filler) may be tubular, in form of honeycomb or cellular type. Earlier single-layer panels were used, but now two-layer panels are used to enhance sound absorption. In addition, multi-layered sound-absorbing circuits are being developed to further noise reduction. A combination of different variants of fillers can be used at the same time. Fillers have not only a function of sound absorption, but also are elements of load-bearing unit, so providing strength of composite structures with fillers in different loads is also important.

The present work is dedicated to experimental-theoretical prediction of effective mechanical properties of sound-absorbing panels and different types of fillers.

We regard one- and two-layer panels of sound-absorbing circuit made of fiberglass and carbon fibers with different types of fillers: tubular, honeycomb and cellular. Computer models of sound-absorbing circuit panels with different cells were created. Calculations of the stress-strain state in the sound-absorbing circuit cells under various conditions of loading and estimates of aggregates strength were obtained using these models. Effective elastic properties of various fillers calculated with help of averaging strain and stress fields. Sound-absorbing circuit panel samples tests for uniaxial tension, compression and shearing were conducted both with perforated and non perforated samples. The test results were compared with numerical simulations. Comparison showed good agreement on experimental results and calculated mechanical behavior of developed models. Estimated breaking load values of sound-absorbing circuit panel corresponded to experimental data. The models allow investigation on cell fillers parameters impact on multilayer sound-absorbing circuit components mechanical properties and evaluate their deformation and strength properties under different loading conditions.
CHARACTERIZATION OF A COMBINED-CORE SANDWICH BEAM MADE FROM CORK AND POLYURETHANE

A. Arbaoui

Laboratoire des matériaux minéraux & composites, Université M’hamed Bougara Boumerdes, Avenue de l’independance, 35000, Algerie

The design of sandwich structures is composed of thin facing and a lightweight core material. These structures have an intense application in various fields such as aeronautics, shipbuilding and engineering civil. The motivation of sandwich structure element is twofold. First for a beam or plate bending normal stresses are absorbed by the skins that are resistant and lightweight core material support shears. These structures also reach appreciable rigidity while minimizing their weight. The commonly used material for sheets is aluminum alloy or fiber reinforced plastics. In the field of civil engineering and, particularly in Algeria, sandwich panels manufacturing has increased enormously in recent years. These structures are based on injected polyurethane in the core and metallic skins. In this work, we propose to introduce a material that is light and natural such as a cork minimizing the polyurethane layer (1cm) to avoid delamination and use external agents to ensure the bonding of various layers. The material used for sheets is Oriented Strand Board. Characterization and bending tests, a long term characteristics (shear modulus) of the core’s material to determine a creep response of the structure were studied.

REFERENCES

STUDY ON THE MECHANICAL PROPERTIES OF SHELLAC FILMS GRAFTED WITH ACRYLIC MONOMERS 2-HYDROXYETHIL METHACRYLATE (HEMA) BY ULTRAVIOLET (UV)

A. Arnautov, V. Korhov, and E. Faitelson

University of Latvia, Institute of Polymer Mechanics, Aizkraukles 23, LV-1006 Riga, Latvia

During the last two decades, considerable effort has gone into the development of natural polymers. Natural polymers are eco-friendly, but they have limitations in the applications with respect to durability, mechanical properties. Shellac is a purified, natural polymer (resinous oligomer MW ≈ 1000 D) of lac insect (Kerria Lacca) grows on some types of trees such as berry in Southeast Asian countries. Shellac consists of polyesters of mainly aleuritic acid, shellolic acid, and a small amount of free aliphatic acids. Shellac has excellent film-forming properties, high gloss, and poor permeability to gases and water vapor. Historically, shellac was mainly used in alcoholic solutions. Shellac (SL) films prepared from alcoholic solutions show pronounced hardening induced by a continuing polymerization process. These are disadvantages when compared with synthetic or partially synthetic polymers such as polymethacrylates and cellulose. Research works have been made to improve mechanical properties of shellac polymers.

Shellac with varying concentrations (3, 5, 7 and 10%) of the acrylic monomer 2-hydroxyethyl methacrylate (HEMA) in ethanol solution were investigated.

Shellac films with the acrylic monomer (thickness 100–300 µm) along with pure shellac were prepared by casting and evaporation. Then 30 ml of the 10% shellac solutions are poured onto teflon plates. The shellac solutions were kept at room temperature for 48 h for film formation. The shellac films are cured under ultra violet (UV) radiation at different doses. Then, dried films were peeled off and cut into specimens with dimensions 7×1 cm². The film samples are stored in a desiccator at room temperature over silica gel until use.

The mechanical properties such as tensile strength (TS), the Young’s modulus (YM) and elongation at break (EB) of the prepared films were studied.

The crosslink density of the films was determined by swelling methods in ethanol solution.

Crossling density \( q \) is defined as the mole fraction of crosslinked units.

\[
q = \frac{M_O}{M_C}
\]

where, \( M_O \) is the molecular weight of the repeated unit, \( M_C \) is the average molecular weight between crosslink, which is directly related to the crosslink density.

The tensile strength of UV cured shellac films showed about 10% enhancement than that of raw shellac films.
A WEDGE-TYPE ANCHORAGE SYSTEM FOR FRP COMPOSITE TENDONS
A. K. Arnautov$^1$, V. L. Kulakov$^1$, A. Kovalovs$^2$, and G. G. Portnov$^1$

$^1$Institute of Polymer Mechanics, University of Latvia, Riga, Latvia
$^2$Riga Technical University, Riga, Latvia

An anchorage system for the tensile load transmission on the circular rods/tendons made from high-strength pultruded composites is proposed. The anchorage system comprises a composite rod having a spitted end with an inserted and glued metal wedge, a metal sleeve and pottant material, connecting composite rod and sleeve. The main objective of the system proposed is reduction of high stress concentration at the loaded end, which is typical for the bond-type anchor systems. The detailed analysis of 3D stress-strain state of the anchor was performed for pultruded CFRP/epoxy rod, steel sleeve, aluminum wedge and epoxy resin pottant. All calculations were made with finite element method accounting for elastic and elastic-plastic behavior of epoxy resin in shear. The principal conclusion resulting from these FEM calculations implies that stress concentration at the loaded end of the anchor system keeps independently of the wedge location if the adhesive bond between composite rod and pottant is available. The possible technical solution of this problem may be creation of a friction interface between composite rod and pottant within the anchorage length. To verify this suggestion, 3D contact FEM problems for the anchor system with the various lengths of friction interface were considered and analyzed. A series of the uniaxial tensile tests were carried out for the anchor systems made with CFRP pultruded rods of 5.5 mm diameter, steel sleeve of 300 mm length, Al wedge of 110 mm length and cone angle of 7° embedded into epoxy resin. These experiments confirmed the working capacity of the anchor system proposed to transfer the tensile load on the high-strength UD CFRP/epoxy rod made by pultrusion. Failure of these CFRP rods was observed at the gauge section and maximum tensile stress of 2038 MPa. The anchor systems were fabricated with adhesive bond and only friction interaction between composite rod and pottant.
EFFECT OF LIGNINS ON THE STRUCTURE AND TENSILE AND THERMAL PROPERTIES OF POLYURETHANES FILMS

A. Arshanitsa, L. Krumina, L. Vevere, and G. Telysheva

Latvian State Institute of Wood Chemistry, Dzerbenes 27, LV-1006, Riga, Latvia

The traditional source of plastic industry, such as fossil fuel reserves, is diminishing and the demand of renewable raw material for polymer production is increasing [1]. Lignin produced as by-product of lignocellulosic chemical processing are recognized as important renewable hydroxyl containing macromonomers for polyurethane (PU) production. The properties of lignins vary depending on methods of their isolation and plant source processed. Correspondingly, origin of lignin influence properties of PU formed.

In this study, the effect of lignin on the properties of PU films obtained from three components systems included polyethelenglykol (Mn=400 g/mol), lignin and commercial diphenylmethane diisocyanate (MDI) Voratec SD 100 (C\textsubscript{NCO}=31%) were investigated.

The organosolv wheat straw lignin was produced on CIMV pilot plant (France) within 7\textsuperscript{th} FP "BIOCORE" Project. Three fractions of lignin were obtained by sequential extraction with dichloromethane, methanol and methanol/ dichloromethane mixture. The functionalities of fractions were completely characterized.

PU films were prepared by pre-polymerization of constituents in extra dry tetrahydrofuran followed by preparation of films by solution casting. The content of lignin fractions in PU varied in the range 5-40\%. Tensile strength, modulus of elasticity and elongation at break were determined using ZWICK testing device at deformation rate 10%/min. The glass transition (T\textsubscript{g}) temperature of PU films was identified on METLER TOLEDO DSC 823 device.

The cross-link density of the PU was determined experimentally by Flory-Rehner method [2].

The increase of cross-link density of PU from 0.24×10\textsuperscript{-3} mol/cm\textsuperscript{3} for PEG-MDI system up to 1.0-1.5×10\textsuperscript{-3} mol/cm\textsuperscript{3} for lignin containing PU films was established. As the results the elastic modulus (E) and tensile strength (\(\sigma\)) of PU films are increased steadily with increasing of lignin content in PU composition. The most pronounced growth was determined for PU contained methanol and methanol/ dichloromethane soluble fractions. For these systems values of \(\sigma\) and E equal 60 MPa and 2.5 GPa, correspondingly, were achieved. The PU films contained dichloromethane soluble fraction of lignin demonstrated lower strength and modulus of elasticity. All PU films displayed a maximum in ultimate strain (170-200\%) at 5-10\% of lignin content.

The increasing of lignin fractions content in urethanes compositions up to 40 \% was accompanied with linear growth of T\textsubscript{g} values of PU films in the range 6\textdegree C-120\textdegree C.

The results obtained show that organosolv lignins of wheat straw acts as a cross linking macromonomer in PU compositions. The fractionation of lignin and variation of fractions contents in PU composition allow to control the properties of PU films and to obtain the elastomers in high elastic state at room temperature or rigid and glassy crosslinked PU.

REFERENCES


RELATION OF COMPOSITION AND PROCESSING PARAMETERS TO STAIN RESISTANCE OF A PARTICLE-REINFORCED POLYMER COMPOSITE

A. Aruniit¹, J. Kers³, A. Krumme², R. Talalaev¹, H. Herranen³, and O. Pabut³

¹Dept. of Materials Engineering, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia
²Dept. of Polymeric Materials, Tallinn University of Technology, Ehitajate tee 5, 19086, Tallinn, Estonia
³Dept. of Machinery, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia

A particle reinforced composite material consisting of the unsaturated polyester resin and the fine dispersion of alumina trihydrate has good mechanical and physical properties. It performs well as laboratory or culinary bench top, in the bathrooms as vanity top or sanitary ware, in maritime and agricultural applications. One of the dominant requirements for these products is stain resistance. Good stain resistance to household products and easy cleaning are the cornerstone for commercial success.

It is important to know which of many components of a composite material has biggest impact on its staining properties [1]. Besides the composition one must not forget the post curing process that is done to obtain extensive crosslinking and enhance the mechanical and physical properties of the polymer composite. A variable, that also has to be considered, is the surface roughness. Surface roughness depends on the moulding and finishing processes.

The aim of the current research was to enhance the stain resistance of a particle filled polymer composite. The objective was to study which components and technological process parameters influence this property. The research took into consideration also the variables like cost, weight, mechanical and physical properties. The results can be carried over to other polymer composites.

The research is based on experimental data. The experimental data was used in mathematical modelling. Hybrid genetic algorithm based numerical procedure was developed [2]. The testing procedure of staining is based on industry recognized ANSI Z124.3 and Z124.6. Test slabs with different composition were fabricated with vacuum assisted extruder. The main components, that were under observation, were resin, filler and colour pigment. Besides that the influence of wt.% of initiator was evaluated. This was followed by testing of post curing and surface roughness parameters. For testing and analyses were used KMSA colorimeter, PerkinElmer DSC-7, SEM electron microscope and Instron 5866 mechanical testing system.

The tests showed that with higher concentration of colour pigment the staining resistance declines. Post curing at 60°C for 12 h was the optimum of stain resistance, mechanical properties and cost. The results improved with lower surface roughness values.

With controlled process parameters and optimised composition good stain resistance properties of particle reinforced composite material are obtainable.

REFERENCES

COMPUTER SIMULATION OF THE DEFECTS IN POLYTETRAFLUOROETHYLENE IRRADIATED BY IONS

K. N. Aryutkin, A. I. Kupchshin, B. A. Kozhamkulov, K. B. Tlebaev, and T. A. Shmygaleva

Abai Kazakh National Pedagogical University, Republic of Kazakhstan

A computer simulation of the distributions of concentrations of implanted impurities and vacancy clusters in depth in polytetrafluoroethylene were carried out. Calculations of the distributions of implanted ions were conducted using the program SRIM, and vacancy clusters in the developed program "The vacancy cluster". The program SRIM has a wide range of settings.

The type of material, the proportion of its atoms of different elements are specified, the thickness of the material, the beam energy and type of incident ions and the beam angle relative to the surface are given. It is possible to specify multiple layers of different materials (study covers and films).

In this paper polytetrafluoroethylene was used as a target, the protons and ions of carbon, iron, fluorine, molybdenum, tungsten were taken as the incident particles. The beam energy was varied from 10 to 100 keV both protons and ions.

The calculation of the concentration distribution of vacancy clusters was carried out within the framework of the cascade-probability method. Herewith the energy loss at passage of ions through the matter calculated from Komarov-Kumakhov’s tables.

It was found that with increasing energy of incident ions the maximum concentration of defects is shifted to the right, but its value decreases. With increasing atomic number of the distribution of implanted ions and vacancy clusters is shifted to the left.
ESTIMATION OF STRENGTH OF THE REINFORCED POLYETHYLENE PIPES IN THE CONDITIONS OF LOW TEMPERATURES

F. I. Babenko, Y. Y. Fedorov, and A. K. Rodionov

Institute of problems of oil and gas of the Siberian Branch of the Russian Academy of Science, Yakutsk, Russia

Earlier, in the quasi-static tests on the tensile strength (speed of testing 25 mm/min) model specimens reinforced polyethylene pipes (RPP) (production of JSC "Sibgazapparat") in the range of climatic temperatures, ductile-brittle transition (DBT) at a temperature of -15°C are revealed. The three-layered structure of the RPP provides for a bonding layer (low density polyethylene, Savilen) connecting the reinforcement (aramid fiber) and polyethylene membrane tube (PE80). According to the terminology of ISO DTS 18226, in the temperature range of test temperatures below DBT "integrity" RPP plastic shells was lost on the mechanism of brittle crack growth and, hence, the "destruction" of construction.

In the present work, we investigated the dependence of rate of test (25 ÷ 100 mm/min) for tensile of model samples on the temperature DBT. Model samples – dumbbell-shaped specimens (type 2, GOST 11262) – are made from RPP diameter 140 mm with a nominal wall thickness of 17.5 mm.

It was experimentally established that with increasing velocity tensile tests of the model samples of this design RPP (from 25 to 100 mm/min and higher), the temperature of DBT increases from -15°C to 0°C.

The fracture mechanism of model sample was studied, interpreted and tested in model experiments with artificially deposited on the surface of polyethylene samples brittle layers. It was observed the cracking of the intermediate layer (or interface), adhesively coupled with layers of polyethylene (inner and outer layers RPP), whose ability to crack retardation defines the transition from ductile fracture to brittle when the temperature tests decreasing. The transition from ductile fracture to brittle defined ductile-brittle transition in the mechanism of destruction of polyethylene layers of RPP, namely the transition to a plane strain at the tip of the breaking crack.

The nature of crack developing in the intermediate RPP layer (or on the boundary) requires a special investigation, without which it is currently impossible to conclusively interpret the random behaviour of the exhibition of DBT in the collapse mechanism of a model sample. In this case, we note that the "spectrum of cracking" of the intermediate layer, which determines brittle fracture in the temperature range of tests is characterized by the following parameters: the strains – 2.0÷6.7%; the stress – 16.4 ÷ 31.7 MPa.
A STUDY ON THE MICROSTRUCTURES AND MECHANICAL PROPERTIES OF AN IN-SITU LIQUID MIXING-PROCESSED FEAL/ZRC INTERMETALLIC MATRIX COMPOSITE

K. C. Bae, J. M. Choi, I. M. Park, and Y. H. Park

Department of Material Science and Engineering, Pusan National University, Busan 609-735, Korea

One of the most widely studied intermetallic system for the applications in structural components is iron aluminides (Fe₃Al and FeAl), which have relatively low cost, low density, good wear resistance, ease of fabrication and excellent resistance to oxidation and corrosion. These advantages have led to the identification of several potential usages of them, including heating elements, furnace fixtures, heat exchanger piping, sintered porous gas-metal filters, automobile and other industrial valve components, catalytic converter substrates and components for molten salt applications. However, at this time there are still some major issues which continue to delay commercial viability of this structure, especially their low ductility and impact resistance at low temperatures and inadequate creep resistance at high temperatures. On the other hand, intermetallic matrix composites (IMCs) such as ceramic particle reinforced intermetallics can offer excellent combination of high-temperature strength, creep resistance and environmental stability with adequate ambient temperature ductility and low density.

This study aims to develop novel iron aluminide based IMCs which have improved mechanical properties than conventional iron aluminide intermetallics, by introducing fine ceramic particles homogeneously using in-situ reaction. For this purpose, in-situ liquid mixing process was applied for the fabrication of IMCs reinforced with in-situ synthesized ZrC particles. The microstructures and mechanical properties of the newly developed IMCs were investigated and compared with conventional casting processed IMCs.
IMPACT BEHAVIOR OF MULTILAYERED $\text{B}_4\text{C}/\text{AA7075}$ FUNCTIONALLY GRADED MATERIALS AGAINST AN ARMOR-PIERCING PROJECTILE

E. Balcı$^1$, B. Sarikan$^1$, M. Übeyli$^2$, and N. Camuşçu$^1$

$^1$TOBB University of Economics and Technology, Mechanical Engineering Söğütözü Cad. No:43 06560 Ankara-Turkey

$^2$Osmaniye Korkut Ata University, Mechanical Engineering Karacaoğlan Yerleşkesi, 80000 Osmaniye-Turkey
e-mail: mubeyli@gmail.com

In this study, the impact behavior of the multilayered $\text{B}_4\text{C}/\text{AA7075}$ Functionally Graded Materials (FGMs) against the 7.62 mm Armor Piercing (AP) projectile was investigated. The FGMs with three layers were produced via hot pressing. At the bottom layer, the monolithic AA7075 alloy was used while at the middle and top layers, the AA7075 composite layers having various proportions of $\text{B}_4\text{C}$ particles were considered. After the micro and mechanical characterizations, an artificial aging treatment at 120 °C for 65 hours was applied to all samples to get the highest hardness values for each layer [1, 2]. The porosity level and grain size of the separate layers for the investigated materials were determined using an image processing program. The ballistic testing of the samples was carried out in a ballistic laboratory using 7.62 mm AP projectiles. In the ballistic testing, five separate specimens for each FGM group having various compositions and thicknesses were used. Moreover, one shot was applied to each target specimen. After completing the ballistic testing, the failure mechanisms for the tested FGMs were examined. Experimental results showed that the ballistic impact resistance of the investigated FGMs increased with increasing boron carbide content and the thickness in the layers. In addition, there were no separations observed between the layers in the failed samples. The ductile hole formation was seen at AA7075 rear layer whereas some radial cracks were observed at the composite layers. Furthermore, highly deformed grains were detected near to the impact zone of the samples.

Acknowledgement. This work was supported by the Research Fund of TÜBİTAK, Project # 110M034. The authors are thankful to TÜBİTAK for its support.

REFERENCES


NONDESTRUCTIVE TECHNIQUES FOR A RELIABLE CHARACTERIZATION OF ADVANCED COMPOSITE MATERIAL PROPERTIES

E. Barkanov\textsuperscript{1}, M. Wesolowski\textsuperscript{1}, P. Akishin\textsuperscript{1}, and S. Belouettar\textsuperscript{2}

\textsuperscript{1}Institute of Materials and Structures, Riga Technical University Kalku St. 1, LV-1658, Riga, Latvia
\textsuperscript{2}Department of Advanced Materials and Structures, Centre de Recherche Public Henri Tudor 66, rue de Luxembourg, L-4221 Esch-sur-Alzette, Luxembourg

Composites like investigated in the present study are seen as an area of high growth in the world due to their intrinsic benefits and critical role in different industrial sectors such as aerospace, land transport, marine and construction. Unfortunately the material data provided by manufacturers very often do not contain all necessary information to predict the behaviour of advanced composite materials using different analyses tools. Additionally, due to high costs of nanocomposites, their experimental testing with the conventional fracture methods suffers from high expenses too. On this reason different nondestructive techniques have been developed for the material properties characterisation and adapted for the testing of nanocomposite samples with small geometrical dimensions. There are static approach using three-point bending test and two dynamic methods, namely, impulse excitation method and inverse technique based on vibration tests.

Three-point bending test allows to determinate the elastic modulus of the material in terms of the measured centre deflection, applied load and geometry of a beam. In order to keep this approach nondestructive, this technique is only applicable for the elastic behaviour of composite beams which can be obtained usually for a strain less than 0.5%. Vibration test based on the impulse excitation is adopted for the determination of elastic properties of composite beams. In this method the main requirement is to establish dimensions, material density, and experimental fundamental flexural and torsion frequencies of a beam with free-free boundary conditions. The inverse technique based on vibration tests consists of the experimental set-up, numerical model and material parameters identification procedure developed by applying a non-direct optimisation method based on the planning of experiments and response surface methodology in order to considerably decrease the computational efforts.

The present nondestructive techniques have been successfully applied to characterise the material properties of laminated carbon/epoxy prepreg panels (Table 1) and aluminium alloys with different carbon nanotubes volume content. The obtained results demonstrate a reliability of the developed methods. Moreover three-point bending test and impulse excitation method can be applied in the first stage of characterisation decreasing by this way the number of design parameters to be found in the inverse technique and accordingly increasing an accuracy of the identified material properties.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
 & Three-point bending & Impulse excitation & Inverse technique \\
\hline
$E_1$, GPa & 117.12 & 115.16 & 116.80 \\
\hline
$E_2$, GPa & 8.95 & 8.62 & 8.85 \\
\hline
$G_{12}$, GPa & - & 4.56 & 4.10 \\
\hline
$\nu_{12}$ & - & - & 0.36 \\
\hline
\end{tabular}
\caption{Material properties of SEAL\textsuperscript{®} Texipreg HS 160 RM.}
\end{table}
INTERFACIAL PROPERTIES OF ALUMINUM/GLASS FIBER-REINFORCED POLYPROPYLENE SANDWICH COMPOSITES

S. B. Baştürk¹, A. Guruşçu², and M. Tanoğlu¹

¹Dept. of Mechanical Engineering, Urla, İzmir, Turkey
e-mail: metintanoglu@iyte.edu.tr
²Dept. of Materials Science and Engineering, Urla, İzmir, Turkey

Fiber-Metal Laminates (FMLs) have various application areas including aeronautical, marine and transportation industry. FMLs containing glass fiber reinforced polypropylene (GFPP) and aluminum (Al) sheet provide advantages of both metals and composites in such systems. The interfacial property of sandwich systems that has different components has critical importance to manufacture those composite structures. In the present study, Al/GFPP laminates were manufactured with various surface pretreatment techniques. Adhesion at the composite/metal interface was achieved by surface pretreatment of Al sheet with amino based silane coupling agent, incorporation of polyolefin based adhesive film and modification with PP based film containing 20 wt. % maleic anhydride modified polypropylene (PP-g-MA). In order to increase the effect of bonding between the components of the FMLs, the combination of silane treatment and PP-g-MA/PP based film addition was also investigated. The mechanical properties (shear, peel and bending strength) of the adhesively bonded Al/GFPP laminates were examined to evaluate the effects of those surface treatments.

Based on the experimental results, the adhesion of the laminated Al/GFPP systems was improved by the treatment of aluminum surfaces with amino-based silane coupling agent. Based on peel and bending strength results, Al/GFPP laminates with the incorporation of polyolefin based adhesive films exhibited significant increase on the adhesive behavior. Modification of Al/GFPP interfaces with PP-g-MA/PP layer led to highest improvement on the adhesion properties. The combination of silane surface modification and PP-g-MA/PP based film addition was expected to increase the adhesion performance, however, the experimental results showed that this combination did not yield the desired high bending strength. This may be due to the insufficient bonding of silane groups with PP-g-MA/PP based film.
RESTORATION OF THE SPATIAL STRUCTURE OF HIGHLY-POREUS POLYURETHANE FOAMS

I. Beverte and A. Zilaucs

Institute of Polymer Mechanics, University of Latvia, LV-1006, Riga, Latvia

Symmetry of structure of composite materials is connected to symmetry of mechanical and physical properties, e.g. free-rise plastic foams are monotropic with plane of isotropy directed perpendicular to the rise direction. A general problem exists how to restore the spatial structure of inhomogeneous materials and materials comprising inclusions of other material (Porous ceramics, porous plastics, concrete reinforced with short metal fibbers etc.) without destructing the material and analysis of each element. For the first time methods of statistical geometry were used for micro structural analysis of crystals, metal melts, minerals, suspensions etc. [1, 2]. The calculations lead to a Gamma-functions and analytical solutions can be found only for several special cases: uniform, rising, decreasing, triangular distribution functions. Experimental methods used, include mercury tests and X-ray diffractometry applied recently to study morphology of bones and plastic foams.

Two cases can be distinguished for plastic foams (e.g. polyurethane and polyvinylchloride): (1) Low porosity P<30%, the foams’ structure is formed by un-interconnected gas bubbles, distribution of their diameters have to be found and (2) High porosity P>90%, the foams’ structure is formed by polymeric struts, distribution of their length and spatial orientation have to be found.

No reliable methods for restoration of the spatial structure of plastic foams from photos are known to the authors. Therefore a method and a model are proposed for highly-porous polyurethane foams, permitting to determine distribution of polymeric struts’: (a) Length and (b) Spatial orientation, using their photos obtained by penetrating light microscope. Monotropy is implemented by a linear coordinate transformation along axis parallel to rise direction. Model is tested on the special cases: uniform, rising, decreasing, triangular distribution functions. Calculations of distribution functions for struts’ length and angles, their mean and standard deviations are performed for foams with space filling coefficient $P1 = 3 – 8\%$; $P1=1 – P$. Distributions conform well to exponential functions of type

$$F(L) = AL^m e^{-aL}$$

where $A$ is a coefficient; $m$, $\alpha$ and $p$ are parameters determining sharpness of maximum and asymmetry of the distribution curve.

The calculation results are compared with experimental data obtained for five free-rise, monotropic polyurethane foams samples with density range $\rho_f = 35 – 80$ kg/m$^3$ and different degrees of monotropy. A good correlation with experimental data is proved to exist. The proposed method and model could be used for orthotropic highly-porous foams, too.

Acknowledgement. The research was performed at EU ERDF funded project 2010/0290/2DP/2.1.1.1.0/10/APIA/VIAA/053.

REFERENCES

USE OF GLASS FRP COMPOSITES FOR THE STRENGTHENING AND STIFFENING OF SLENDER WEB PANELS OF STEEL I-BEAMS

M. A. Bhutto¹ and I. M. May²

¹School of Built Environment, Heriot-Watt University, Edinburgh, UK, e-mail: mb284@hw.ac.uk
²School of Built Environment, Heriot-Watt University, Edinburgh, UK, e-mail: i.m.may@hw.ac.uk

Due to the high strength and stiffness properties as well as durability and light weight, fibre-reinforced polymers, FRPs, or advanced polymer composites, APCs, have been extensively and successfully used in the strengthening, repair and rehabilitation of concrete and steel structures. In the FRP-strengthening of steel beams, the main focus of research work carried out has been to increase the flexural and shear strength of the beams. Little attention has been given to increase the out-of-plane stiffness of thin-walled steel beams where failure is initiated due to shear buckling of the web panels. This paper presents results of an experimental and numerical investigation carried out to investigate the use of FRP composites for the strengthening and stiffening of slender web panels in steel I-beams. The web panels were strengthened by bonding pultruded sections of glass-fibre reinforced polymer, GFRP, composites as additional stiffeners to increase their stiffness and to provide them with increased resistance to the tendency to buckle out-of-plane because of the high applied shear force. The ends of GFRP stiffeners were tapered to minimize the shear stresses in the adhesive at its ends to avoid debonding of the GFRP. The test results showed that the ultimate load capacity of the GFRP-strengthened specimen was increased by approximately 20%, compared to that of the un-strengthened control specimen. The strengthening technique delayed initiation of shear buckling of the web panel. No sign of any debonding or delamination of the GFRP-stiffeners was observed at the ultimate load of the strengthened specimen. Before testing, linear eigenvalue and non-linear finite-element analyses of the un-strengthened and the GFRP-strengthened specimens were performed. The ultimate and buckling loads and the modes of failure predicted by the FE analyses were in good agreement with the test results.
LOW-TEMPERATURE EFFECT ON THE MECHANICAL PROPERTIES OF GLASS- AND CARBON-REINFORCED/EPOXY COMPOSITES AND FML

J. Bieniaś, B. Surowska, and K. Majerski

Dept. of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Poland

In recent years, composite structures have become very popular materials for different applications, predominantly in the aerospace industry. Their large spectrum of properties like strength and stiffness-to-weight ratios, fatigue characteristics and corrosion resistance comprise several extremely distinctive advantages for application in lightweight primary structures. One of the main and significant purposes is to guarantee the durability and safety of the structures. Fibre metal laminates (FML) provide very good combination of metals and composites. In composites one or more of damage mode, e.g. matrix cracking, matrix yielding, interfacial debonding and delamination, fibre breakage or pull out can produce failure. FML’s have superior resistance to crack growth because of the fibre bridging effect.

It is very significant in applications how the mechanical properties change under low temperature condition. It is known that at low temperatures, the epoxy matrix becomes stiff and brittle, enhancing the crack opening restraining, resulting in a reduction in the stress intensity factor. On the other hand the resistance of aluminium (used in FML) to fatigue crack growth increases at low temperatures, which adds to the beneficial effect on the fatigue behaviour induced by the stiffer fibre layers.

The materials investigated in this study were unidirectional glass fibre and carbon fibre/epoxy composites and aluminium alloy/fibre reinforced epoxy composites laminates manufactured by autoclave method. The aircraft HexPly (Hexcel) prepregs and 2024T3 alloy were used as components.

Samples were tested in tension test at room (RT) and cryogenic temperature (153 K). The tension test was carried out on a MTS hydraulic axial loading test machine (with liquid nitrogen environment climatic chamber) in accordance with ASTM D3039. Fractography analysis of samples was also performed on optical and scanning microscopes.

The result of the study is presented in a force-elongation diagram, from which the value of maximal force was read directly. The values of ultimate tension strength and modulus of elasticity are calculated in the same way for RT and cryogenic temperature.

Fractography identified the brittle fracture especially in epoxy matrix after cryogenic test. However the tensile strength and Young’s modulus of composites and laminates FML increase in low temperature.

Acknowledgement. This work is carried out with financial support of Structural Funds in the Operational Programme – Innovative Economy (IE OP) financed from the European Regional Development Fund – Project No POIG.0101.02-00-015/08.

REFERENCES

THE MECHANICAL PROPERTIES AND FAILURE ANALYSIS OF SELECTED FIBRE METAL LAMINATES

J. Bieniaś and B. Surowska

Dept. of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36, Lublin, Poland

Composites are actually advanced engineering materials having wide range of applications in aerospace. A new generation of composites are Fibre Metal Laminates based on thin sheets of metal alloy alternately bonded with layers of fibre reinforced polymeric materials. This combination produces a material which possesses significant improvements in some or all properties including high strength-to-weight and stiffness-to-weight ratios, fatigue, impact resistance, low density, corrosion and fire resistance. The most common method used to produce FML is autoclave processing (under relatively high pressure, vacuum, elevated temperature).

Currently, a number of aerospace manufacturers are focusing their attention on the design and production of laminates with different metal alloys and fibres reinforced polymers (titanium, carbon fibres). Because hybrid laminates are a relativity new material technology, the material properties need to be characterized.

The aim of the present work is to investigate the selected mechanical properties of hybrid FML-laminates based on aluminium and titanium and composites with carbon and glass fibers reinforced epoxy. Laminates were characterized by mechanical properties (tensile strength, Young's module) and the process of failure, depending on the configuration of layers in the composite material. In comparison to base metal alloy significant increase in mechanical properties for FML’s was obtained. The main factors that influence the properties of laminates are: the type of individual components: metal alloys, and fibre-epoxy composites and the orientation of reinforcing fibers. The failure of FML’s indicates the complexity process of degradation of these materials. The nature of damage in layers of polymer composite is similar to that typical for this type of materials. At the interface between the metal and composite material observed mixed nature of the damage - cohesive and adhesive. FML’s are a group of hybrid materials with potential uses including air structures, often replacing traditional metal alloys or polymer composites reinforced with fibers.

Acknowledgement. This work is carried out with financial support of Structural Funds in the Operational Programme – Innovative Economy (IE OP) financed from the European Regional Development Fund – Project No POIG.0101.02-00-015/08.

REFERENCES
IMPACT BEHAVIOUR OF FIBRE METAL LAMINATES

J. Bieniaś

Dept. of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36, Lublin, Poland

Fibre Metal Laminates (FML) are hybrid materials, consisting of alternating layers of thin metal sheets and composite layers (Fig. 1). FML possess superior properties of both metals and fibrous composite materials. Fibre Metal Laminates are characterized by excellent damage tolerance: fatigue and impact and characteristics, low density, corrosion and fire resistance. Current and future research on FML is focused on generating new laminates, for example based on the combination of carbon fibres reinforced polymers.

In the present paper, the impact damage resistance of various Fibre Metal Laminates based on Al alloy and GFRP and CFRP were determined.

The lay-up scheme of the FML composites were 2/1 and 3/2 (stacking sequence of polymer composites were [0], [±45], [0/90]). The FML composites have been produced by autoclave technique. Low velocity impact tests were conducted by using a drop-weight tower with spherical impactor (1/2”) based on ASTM D7136 standard. The specimens were impacted at three energy levels of 10, 20 and 25 J.

Fig. 1. Fibre Metal Laminate-2/1 (left); Impact damages in Al/GFRP (centre) and Al/CFRP (right) with impact energy of 25 J.

The impact damage resistance was characterized by the dent depth, the maximum cracking energy and the width of the damaged area. In addition, the relationships between damages observed and impact responses of the different sequence of laminates were explained.

Increasing impactor energy causes more fractured layers, more debonding and delaminations area. The results showed that damage consisting of delamination, matrix cracking, and fiber failure. Based on the observations it was concluded that the impact behavior of FML can significantly influenced by type and stacking sequence of polymer composites.

Financial support of Structural Funds in the Operational Programme – Innovative Economy (IE OP) financed from the European Regional Development Fund – Project No POIG.0101.02-00-015/08 is gratefully acknowledged.

REFERENCES

PHYSICOMECHANICAL PROPERTIES OF A POLYETHYLENE/CARBON
NANOTUBE COMPOSITE PREPARED USING A CONCENTRATE
OF NANOTUBES IN POLYETHYLENE

J. Bitenieks, R. Merijs Meri, J. Zicans, R. D. Maksimov, and E. Plume

1Riga Technical University, Institute of Polymer Materials, Azenes St., 14/24, Riga, LV-1048 Latvia
2Institute of Polymer Mechanics, University of Latvia, Aizkraukles St. 23, Riga, LV-1006, Latvia

Carbon nanotube reinforced polyethylene having increased electrical, thermal mechanical and other physical properties shows good perspective as advanced nanocomposite material. Among other fillers, carbon nanotubes (CNTs) are an especially attractive class of inclusions because of the small amount of CNT filler is needed to achieve results demonstrated in this research. On the other hand, in processing stage of CNT polymer nanocomposites good CNT dispersion in polymer matrix should be taken into consideration.

Results of an investigation into the physicomechanical properties of polyethylene (PE) with small, no more than 5 wt. %, additions of multi-wall CNTs are reported. Specimens of composite were prepared using concentrate, containing 31.6 wt. % of nanotubes in polyethylene matrix. Concentrate were fabricated by patented in situ polymerization technique. CNT polyethylene nanocomposites were prepared by mixing PE/CNT masterbatch and PE powder at desired concentrations and then compounding with two roll mills. CNT content in obtained composites was 1, 2 and 5% by weight. Samples for various tests were made by compression moulding and injection moulding. Experimental data on the influence of CNTs additions on the differential scanning calorimetry (DSC) thermograms and crystallinity of polyethylene matrix are obtained. The results of a thermogravimetric analysis (TGA) for samples heated in an oxidative environment from 25 to 800°C are reported. The thermo-mechanical properties were examined by Dynamic Mechanical Thermal Analysis. Data on the influence of CNTs content on the indices of mechanical properties of PE/CNT in tension (strength, yield stress, elastic modulus, ultimate elongation, and long-term creep) are also presented. The theoretical analysis of elastic properties of PE/CNT composite was carried out by using the Mori–Tanaka theory of an equivalent medium. The calculation results are compared with experimental data.

In general this work provides a simple and quick way for the preparation of PE/CNT nanocomposites by processing a commercial masterbatch using melt mixing technique. Results of the investigation on the stress-strain characteristics of CNT filled PE nanocomposites shows that along with increasing weight content of CNT modulus of elasticity E and yield strength σ exponentially increase to the certain maximum. DSC and TGA results show that some calorimetric and thermal properties of PE/CNT nanocomposites are affected by CNT concentration as well.
SOME PROPERTIES OF POLYOLEFINS TOUGHNEd WITH ELASTOMERS MODIFIED AND UNMODIFIED WITH A NANOFLiLLER

I. Bochkov\textsuperscript{1}, R. Merijs-Meri\textsuperscript{1}, T. Ivanova\textsuperscript{1}, J. Grabis\textsuperscript{2}, and R. Kotsilkova\textsuperscript{3}

\textsuperscript{1}Institute of Polymer Materials, Riga Technical University, Azenes Str. 14/24, LV-1048 Riga, Latvia
\textsuperscript{2}Institute of Inorganic Chemistry, Riga Technical University, Miera Str. 34, LV-2169, Salaspils, Latvia
\textsuperscript{3}Department of Physico Chemical Mechanics, Institute of Mechanics, Bulgarian Academy of Science, Acad. G. Bontchev Str., Block 1, Sofia, 1113, Bulgaria

Polyolefins are most useable thermoplastic materials. Polypropylene (PP) and low density polyethylene (LDPE) are used for a long time as main polymeric materials for packaging, automotive, construction and building applications. According to last European commission statistic data in Europe 8.82 Mtons of PP and 7.89 Mtons of LDPE were consumed in 2010 (19 and 17 % from the total polymer generation sector, respectively).

Both of them are good for some applications, but at the same time they have some disadvantages that limit their use. For PP they are thermooxidative stability and low impact resistance. For LDPE they are low properties in comparison with materials, obtained by using new generation synthesis technologies. Consequently, it is necessary to modify them, to obtain materials with advanced properties.

To obtain material with new or advanced properties we used ethylene-1-octene copolymer (EOC) as organic modifier. Recent development in metallocene catalyst allows synthesize ethylene copolymers with other high olefins, possessing narrow molecular weight and homogeneous co-monomer distribution. Plasma synthesized ZnO nanoparticles, in its turn were used as inorganic functional modifier, allowing improve thermo and dimensional stability of the material along with other exploitation and technological properties.

Composites were obtained by using twin-screw co-rotating extruder. The content of elastomeric modifier was changed from 0 to 100 wt. %, while that of inorganic modifier - from 0 to 10 wt. %. Temperature profile was 160-200° C for PP and 150-185° C for LDPE matrix composites. Testing samples where obtained by compression molding at 190 °C (PP matrix compositions) and 160° C (LDPE matrix compositions).

In the current work, results of the investigations on the manufacturing technology of the above mentioned polymer blends and polymer nanocomposites are demonstrated. In addition results of mechanical, dynamic, reological and structural properties of various PP/EOC compositions and selected nanocomposites with ZnO are presented.

Deeper investigation of such systems allows us get better overview on multifunctional nature of the above mentioned composites.
MECHANICAL PROPERTIES AND STRUCTURE OF A MWCNT/EPOXY RESIN NANOCOMPOSITE

A. Borisova¹, T. Glaskova¹, K. Aniskevich¹, K. Kundzins², and E. Faitelson¹

¹Institute of Polymer Mechanics, University of Latvia, LV-1006, Riga, Latvia
²Institute of Solid State Physics, University of Latvia, LV-1063, Riga, Latvia

Due to the intensive production of different nanoscale filler and various resin type polymer composites the great attention is given to research of properties of nanocomposite (NC) materials. Nanofiller in composite material is capable to improve many characteristics at filler content much lower than in comparison with a micro or macro sized composite filler. The properties of carbon nanotubes (CNTs) are widely investigated for the improvement of material characteristics in the last years. For example, mechanical and thermophysical properties of material are widely investigated for working out of new materials in engineering. One of the important parameters is the filler content in NC. That’s why it is necessary to perform experimental investigation of NC physical properties in order to determine the optimal filler content for the improvement of its functional properties.

The aim of the current work is to establish the mechanical and thermophysical properties of the epoxy resin nanocomposite filled with CNTs depending on their content.

Bisphenol A epoxy resin LH 289 and curing agent H 289, as well as masterbatch with 5 wt. % multiwall CNT were used for sample preparation. Epoxy resin and hardener were manually mixed for 5 minutes, degasified for 10 minutes in vacuum atmosphere, and cured for 22 hours at 15 ºC and for 2 hours at 50 ºC. After that the NC samples were post-cured for 24 hours at 80 ºC. Dogbone type samples with different CNT contents (0, 0.2, 0.5, 1.0, 1.9, and 3.8 wt. %) and with dimensions 150×10×4 mm were manufactured in silicon moulds. All the NC specimens were polished at the end to get the flat surface.

The elastic and viscoelastic properties of the epoxy resin and NC with different concentrations of CNT were studied out by tensile quasistatic and creep tests. Quasistatic tensile tests at displacement rate 5 mm/min were performed in order to determine effect of CNT on elastic properties of NC and to choose the stress levels for creep experiments. Based on the results obtained three stress levels corresponding to 1/4, 1/3 and 1/2 of tensile strength were chosen. The creep experiments lasted for 5 hours following 19 hours of creep recovery. The structure of investigated material was studied by scanning electron microscopy using fracture surfaces of NC specimens. The thermophysical properties of the NC were investigated using dilatometry method.

Creep compliance curves were approximated using Boltzmann-Volterra equation and stress-and temperature-time analogies. The obtained retardation spectra were analyzed. The correlation between mechanical and thermophysical characteristics of NC was estimated. Due to relatively high elastic modulus of epoxy resin it remains invariable at investigated filler contents. With addition of CNTs the upper yield stress of NC decreased up to 8%, but tensile strength increased up to 18% and strain at break up to 38% in comparison with unfilled epoxy. Obtained results show that coefficient of thermal expansion of CNT filled NC decreased by 40%, but glass transition temperature slightly increased at medium CNT content. As a result of creep tests the creep compliance of NC with the maximal CNT content was decreased by app. 30% at all stress levels. Based on complex research for the studied NC specimens most of the obtained data revealed the filler content of CNT 1 wt. % as the optimal content with the highest elastic and thermophysical properties.
TIME EFFECT ON HSC WITH AND WITHOUT ADDITION OF FIBERS

O. Cazan and C. Măgureanu
Dept. of Structures, Technical University of Cluj-Napoca, România

This paper presents the influence of polypropylene (PP), steel and hybrid fibers (PP and steel) on the physico-mechanical properties of high-strength concrete of C80 grade.

The following table shows the properties of the fiber reinforcement used in this study:

<table>
<thead>
<tr>
<th>Type of fiber</th>
<th>PP</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity [g/cm³]</td>
<td>0.91</td>
<td>2.85</td>
</tr>
<tr>
<td>Tensile strength [MPa]</td>
<td>300-400</td>
<td>2000</td>
</tr>
</tbody>
</table>

The quantity of the fibers used to reinforce the concrete is expressed as a percentage of the volume of concrete. Three different percentages were studied:
- specimens containing 0.30% of PP fibers;
- specimens containing 0.60% of steel fibers;
- specimens containing a hybrid mix of 0.30% PP and 0.60% steel fibers.

Curing of the specimens was conducted according to standard procedures. They were cured in water with a temperature of $T = 20\pm2°C$ for 28 days, after which they were stored in a climatic chamber ($T = 20\pm2°C$, RH = 60±5%).

The physico-mechanical properties of the concrete that was studied are (Fig. 1):
- compressive strength ($f_{cm}$): determined on 150 mm cubes, loaded up to failure at a rate of 1 MPa/s (Fig. 1.a).
- tension by splitting ($f_{ct,sp}$): determined on 141 mm cubes, loaded up to failure at a rate of 0.1 MPa/s (Fig. 1.b).
- flexural tensile strength ($f_{ct,fl}$): determined on 100×100×550 mm prisms, loaded up to failure at a rate of 0.1 MPa/s (Fig. 1.c).
- modulus of elasticity ($E_{cm}$): determined on 100×100×300 mm prisms, loaded and unloaded at a rate of 0.1 MPa/s, between 0.05 $f_{cm,pr}$ and 0.4 $f_{cm,pr}$ until the stabilization of strains was achieved (Fig. 1.d).
- energy absorbtion ($G_f$): determined on 40×100×475 mm prisms, loaded up to failure at a rate of 100 μm/min (Fig. 1.e).

This physico-mechanical properties were determined at different ages, respectively at 1, 3, 7, 28 and 56 days.

Fig. 1. Tests carried out on HSC specimens.

The curing of the specimens and all the test were carried out in accordance with RILEM – Technical Recommendation for Testing and Use of Construction Materials.
HEAT TRANSFER ENHANCEMENT OF COMPOSITE METAL HEAT-EXCHANGING SURFACES

R. Chatys and L. J. Orman

Kielce University of Technology, Poland

Boiling heat transfer enables to dissipate significant heat fluxes. However, if the heater surface is modified with the application of special coatings such as metal wire mesh structures, even much higher heat fluxes can be transferred. Moreover, these porous coverings enable to extend the advantageous regime of nucleate boiling into regions of film or transition boiling.

Wire mesh coatings are applied onto the heater surface mainly through mechanical means or by sintering. In the proposed paper the sintering method was used for sample preparation. The sintering process occurred at the temperatures of about 900°C in the reduction atmosphere (N\textsubscript{2}, H\textsubscript{2}), so that oxidation could be avoided.

The paper presents results of distilled water and ethyl alcohol nucleate boiling heat transfer under ambient pressure. The tests were conducted on copper surfaces covered with wire mesh coatings made of copper, bronze and brass. These heat exchanging surfaces were compared to each other in terms of their thermal performance. The porosity and wire mesh parameters of each covering (wire diameter, aperture) were the same for different materials so that only the impact of the material used could be determined.

The use of such porous coatings enhances boiling heat transfer comparing to the smooth reference surface. The heat flux for the coated heater can be several times higher than for the smooth surface without such coating at the same superheat (defined as the difference between the wall and saturation temperatures). The use of coatings made of different materials (and, consequently, of different thermal conductivities) can significantly impact the heat flux transferred at a given superheat.

The experimental analysis and the understanding of the physical effects during boiling on surfaces with porous coatings can lead to the elaboration of a precise model of this phenomenon, which is still not available in the literature.
THE EFFECT OF THE DISTRIBUTION OF STATIC STRENGTH AND FATIGUE LIFE ON THE DESTRUCTION OF A FIBER COMPOSITE USING THE MARKOV CHAINS THEORY

R. Chatys$^{1,2}$

$^1$Kielce University of Technology, Poland
$^2$Institute of Polymer Mechanics, University of Latvia, Riga, Latvia

An analysis of the correlation of the static strength and the fatigue life of a unidirectional glass composite has been carried out using the Markov chains theory. The parameters of the Markov fatigue life model are connected with the local static strength parameters of a component composite.

It is necessary to analyze thoroughly the test results, and particularity to check the hypotheses of the strength distribution of composite components and the laminate material. The analysis concerned with the average standard deviation of the statistical strength for different lengths of the fiber bundles and the polyester-matrix laminate samples. The distribution was determined using the OSPPT criterion [1], which states that the OSPPt statistical should not exceed the assumed Calfa criterion limit at $\alpha = 0.05$. The hypotheses were analyzed for both normal and log-normal distribution.

Simple relationships were used to modify the failure model of the laminate composite, taking into account the operational and technological factors in order to estimate the strength and fatigue life of the laminate.

The distribution of the composite static strength and the possibilities of the description of the fatigue life and the static strength using the Markov chains have been investigated. The results of data processing of the static strength and fatigue tests using unidirectional composite specimens manufactured of unidirectional polyether resin (HAVELpol.2) glass fabric UDO® E type are reported.

REFERENCES

DETERMINATION OF THE SIZE OF THE REPRESENTATIVE VOLUME ELEMENT FOR THE ELASTOPLASTIC BEHAVIOR ANALYSIS OF POROUS METAL STRUCTURES

Y. J. Cho, S. O. Yim, I. M. Park, and Y.H. Park

Dept. of Material Science and Engineering, Pusan National University, Busan 609-735, Republic of Korea

Porous metal structures are a class of materials which exhibit unique combination of mechanical properties and energy absorption behaviors, which make them attractive in a number of engineering applications such as light-weight structures and energy absorption components. Since the properties of the porous metals are strongly influenced by their microstructures such as porosity, pore shape and interactions between pores, the numerical analysis plays a key role to understand about the relationships between the microstructure and properties required for design and further development of these materials. For the micromechanical analysis purpose, the pores inside the microstructure can be considered as inclusions which have zero-stiffness. Hence, numerical methods such as representative volume element (RVE) approach, which generally has been used for the composite materials, may be very helpful to analyze and design this kind of materials.

Numerical RVE approaches have been extensively studied in the literature, especially for the prediction of properties of composite materials. Many researches have shown that reliability and accuracy of a RVE model increase with increasing the size of the RVE (e.g. number of inclusions in the model). It was also previously revealed that the size of RVE depends on the morphologies of microstructure, contrast in properties of the constituents and their volume fraction ratio. Concerning of required computational resources, the size of the RVE should be as small as possible for affordable simulation time but at the same time it should be also large enough to insure the reliability of the results. As far as the authors acknowledge, there is no study in the literature so far focusing on the proper size of RVE for the porous microstructures. In this present work, the effect of RVE sizes on the reliability of the model was investigated in order to access the proper RVE sizes for various porous metal structures. A statistical-numerical analysis was performed for the elastic-plastic responses of the RVE models with varying RVE sizes.
A STUDY ON FLEXURAL PROPERTIES OF SANDWICH STRUCTURES WITH FIBER/METAL LAMINATES FACE SHEETS

S. Dariushi\textsuperscript{1} and M. Sadighi\textsuperscript{1}

\textsuperscript{1}Mechanical Eng. Dept., Amirkabir University of Technology, Tehran, Iran

Sandwich structures are consist of a thick lightweight core that can be made from balsa wood, foam or honeycomb and two thin face sheets typically made from metal sheets or fiber composite layers, both have some advantages and disadvantages. Metal sheets are heavy but have better resistance and continuity against transverse loads. On the other hand, although, fiber reinforced plastics have the benefit of being lighter comparing to metal sheets, they are susceptible to the formation of large areas of internal damage when subjected to lateral loads specially impact events and more vulnerable to the environmental effects. Therefore, suitable combination of these two materials results in a hybrid material with superior properties named Fiber-metal laminates (FMLs). FMLs are layered materials based on stacked arrangements of metal sheets and fiber-reinforced plastic (FRP) layers. FMLs have been shown to provide excellent fatigue and impact resistance, high specific static properties, flame resistance and ease of manufacture and repair \cite{1, 2}. Hence for this study, a novel hybrid material system, made up of Glass-Epoxy/Aluminum (GE/AL) laminates face sheets and foam core are fabricated and tested for three-point bending. Also, the effect of face sheets stacking sequence on flexural properties of these sandwich panels was investigated.

The materials used for manufacturing of specimens were aluminum 1050 AA sheets with 0.5 mm thickness, unidirectional glass fiber (E-glass, 400 g/m\textsuperscript{2}), epoxy resin (Axson, Epolam 2002 resin with Epolam 2002 hardener) and polyurethane foam (35 kg/m\textsuperscript{3}). FMLs were made by hand lay-up in two groups with different layer arrangement and bonded to foam cores. Specimens tested by ZWIK (60 tons) apparatus according to ASTM C 393.

Also, a geometrical nonlinear theory based on classical sandwich theory is used to predict force-deflection curves. In this model higher order terms in strain displacement relations are considered. The materials are assumed to be linear elastic. The governing equations are derived using principle of minimum potential energy for simply supported sandwich beams in three point bending conditions.

The results show that the sandwich beams with FML face sheets have higher load carrying capacity than sandwich beams with monolithic metal or composite face sheets. Comparing first group of specimens (Al/GE/GE/Al/core/Al/GE/GE/AL) with second group of them (Al/GE/Al/GE/core/GE/Al/GE/AL) shows that attaching FRP layer of FMLs to foam core leads to better connection between skins and core. Also, the analytical model was applicable to predict flexural properties of sandwich beams and showed good agreement with experimental results.

REFERENCES

This talk is concerned with experimental investigation and constitutive modeling of the viscoelastic and viscoplastic responses of polypropylene/nanoclay composites with various clay contents subjected to uniaxial tensile cyclic deformation with a stress-controlled program (ratcheting between various, but fixed, maximum and minimum stresses).

Hybrid nanocomposites were manufactured in a two-step process [1]. At the first step, a masterbatch was prepared in a twin-screw extruder with clay/compatibilizer proportion 1:2 (maleic anhydride grafted polypropylene was used as a compatibilizer). At the other step, the masterbatch was mixed with polypropylene in an injection-molding machine at various proportions corresponding to nanoclay concentrations $\chi = 0, 1, 2, 3$, and 5 wt.%. Observations in ratcheting tests with various maximum stresses and the zero minimum stress demonstrate a substantial effect of nanofiller: reinforcement with 1 to 2 wt.% of clay results in strong (by several times) reduction of maximum and minimum strains per cycle and pronounced (by two orders of magnitude) growth of number of cycles to failure compared with neat polypropylene [2].

To rationalize these findings, a constitutive model is developed in cyclic viscoelastoplasticity of hybrid nanocomposites with semicrystalline matrices. Adjustable parameters in the stress-strain relations are found by fitting the experimental data. The model describes correctly growth of ratcheting strain in low-cycle fatigue tests and shows that fatigue failure is driven by a pronounced increase in plastic strain in crystallites [3].

To evaluate the effect of loading conditions on material parameters in the constitutive equations, experimental data in cyclic tests with the stress-controlled program are compared with observations in tests with a strain-controlled program (oscillations between fixed maximum and minimum strains) and a mixed program (oscillations between various maximum strains and the zero minimum stress). Numerical simulation confirms ability of the model to predict stress-strain diagrams under cyclic deformation.

REFERENCES

ALIPHATIC POLYAMIDE– 66 HIGH-FILLED WITH ALUMINIUM OXIDE FIBERS

V. I. Dubkova, N. P. Krutko, L. V. Ovseenko, and V. G. Komarevich
Institute of General and Inorganic Chemistry of NAS Belarus, Minsk, Belarus
e-mail: dubkova@igic.bas-net.by

The intensive researches on a creation of the polymeric nanocomposites of various functional purposes including of the small amounts of the additives of nanodimensional range are being conducted now. However in the conditions of the increased demand for the polymeric composite materials and growing deficiency of the raw materials resources which are needed for manufacture of the polymers and also high cost of them, the task of reduction of polymeric component in the compositions with maintenance of the set technical and operational characteristics is represented not less actual.

The purpose of the present work is the development and researches of the properties of thermoplastic composites on a basis of aliphatic polyamide–66 with high degrees of filling by aluminium oxide fibers. Fibers Al₂O₃ were received by thermal treatment of the aluminium carbon fibers at the temperature 800°C on air. Such fibers consisting from the nanograins of aluminium oxide keep a fibril structure peculiar them precursor and not collapsing at a thin grinding for reception of dispersions. Dispersions of the aluminium oxide fibers were introduced at the polyamide in amount of the 5–75 wt. %. The samples of the composites were received by the thermal compacting method. The samples of the polyamide unfilled were made in the same conditions for comparison.

Ambiguous influence of aluminium oxide fibers on physico-mechanical properties of the polymer filled at the growing maintenances of dispersions of the Al₂O₃ fibers in a polyamide matrix has been established. Hardness and dynamic modulus of elasticity of the composites received decrease in comparison with unfilled polymer at the degree of filling of polyamide – 66 by the aluminium oxide fibers up to 30 wt. %. Character of deformation at rise of the temperature in the conditions of the set static pressure in the composites including of the 5–30 wt. % of the fiber filler is practically identical polyamide unfilled. At the same time a wear resistance and frictional parameters are noticeably improved already at the filling degree of polymer by the 5 wt. % of the Al₂O₃ fibers.

Sharp change of the mechanical properties of the composites aside increases is observed at filling of the polyamide by the Al₂O₃ fibers above 30 wt. % and reaches a maximum at the 70% their contents when the whole of polymer practically exist in a superficial layer. The structure and properties of this layer are determined by the physical and chemical processes proceeding on filler-polymer interface. The results of researches of molecular mobility of polymer in the polyamide composites received by the electrophysical and thermomechanical methods of the analysis testify to the deep transformations occuring in system, resulting to formation of the rigidly connected structure. As consequence to this the hardness of the composites at filling of the 50 and 70 wt. % grows at the 1.3 – 1.8 times, the dynamic modulus of elasticity at the 1.36 – 1.77 times, density at the 1.42 – 1.67 times accordingly. The polyamide composite materials developed are intended for use as the products and details of designs in the various areas of the sciences, technical equipment and the industry.
DESIGN AND FABRICATION OF COPPER AND HYBRID EPOXY COMPOSITE MATERIAL BY USING THE HAND LAY-UP TECHNIQUE

S. Duraisamy¹ and K. Arumugam²

¹Dept. of Energy Technology, Royal Institute of Technology, SE-100 44, Stockholm, Sweden  
² Dept. of Mechanical Engineering, K.S.Rangasamy College of Technology, Tamilnadu, India

This paper aims at introducing new reinforcement constituents for use as filler in a polymeric matrix enabling production of cost effective and biodegradable composites. The material was prepared in a mixture of epoxy and hardener at a ratio of 4:1 and mixed with chopped and continuous reinforcement constituents to fill up the mould cavity using hand layup technique. The detailed design of the copper metal reinforced and hybrid fiber reinforced epoxy composite material, which suits the criteria for manufacturing, is also illustrated. The mould for the test specimens is prepared and the reinforcement constituents are mixed with resin in the ratio of 40:60. The wear and friction test is performed on the continuous and discontinuous copper epoxy composite material, whereas the tensile test, flexural test, impact test and water absorption test is performed as per ASTM standards on the sisal, glass and hybrid fiber reinforced epoxy composites. The wear and friction test is performed on the hybrid epoxy composite material using pin-on-disc tribometer. Initially, the thickness of the copper wire is measured using the air wedge experiment, which is then required for calculations. Finally, the mechanical and wear properties of the material are evaluated and analyzed using graphical interpretation. The copper epoxy materials are used for manufacturing electrical and electronic components, whereas the hybrid epoxy composite materials are used for manufacturing structural components of an automobile. The results of the water absorption test show that the hybrid epoxy composite materials absorb low percentage of water, which avoids the volumetric expansion of the material.

REFERENCES

PROGRESS IN HIGH-PERFORMANCE CONTINUOUS NANOFIBERS FOR STRUCTURAL NANOCOMPOSITES

Yu. Dzenis

Department of Mechanical and Materials Engineering, Nebraska Center for Materials and Nanoscience, University of Nebraska-Lincoln, Lincoln, NE 68588-0526, USA
e-mail: ydzenis@unl.edu

Development of advanced fibers and composites in the second half of the 20th Century has revolutionized the field of structural materials. However, new fiber development has been mostly evolutionary in the last two decades. It is well-known that fiber properties can increase dramatically with their diameter decrease. However, conventional mechanical spinning techniques cannot produce fibers with diameters smaller than about two micrometers. Most reinforcing fibers are many times that diameter due to trade-offs between cost and reliability. Recently, there was a rapidly growing interest in using nanotechnology to further improve fiber properties. Carbon nanotubes have been used as nanoreinforcement in polymer and carbon fibers and pure CNT fibers have been produced by several techniques. However, the formidable issues with CNT alignment, high volume fraction, interfacial stress transfer, and the potential health issues are yet to be resolved and no CNT superfiber has yet been demonstrated. This presentation will review the state-of-the-art and recent breakthroughs in the author’s group on an alternative nanotechnology, i.e. continuous nanofibers produced by electrospinning. Recent progress on nanomanufacturing of individual nanofilaments and nanofiber assemblies will be discussed. Prospects of modeling-based precision nanomanufacturing of complex hierarchical 2D and 3D nanofilamentary architectures will be analyzed. Results of extensive nanomechanics testing of several types of individual nanofibers and pioneering discovered nanoscale size effects will be presented and discussed. Unique new simultaneously superstrong/tough continuous nanofilament for structural applications will be reported for the first time. Mechanics of nanofiber assemblies and networks will be analyzed based on experiments and simulations. Possibility of further significant improvement of fiber strength and toughness by controlled lateral interaction of nanofilaments will be demonstrated. Recent breakthroughs on nanofiber-reinforced supernanocomposites (defined as nanocomposites exceeding the properties of conventional advanced composites [3]) will be presented and discussed. Recommendations on the cost-effective designs of structural nanocomposites for near-to-medium term applications will be formulated. Brief overview of other nanofiber uses will also given, including applications in biomedicine and sensors/actuators.

REFERENCES

EFFECTIVE EQUATIONS FOR COMPOSITES WITH VISCOELASTIC AND PLASTIC COMPONENTS

M. E. Eglit\textsuperscript{1} and T. A. Yakubenko\textsuperscript{2}

\textsuperscript{1}Lomonosov Moscow State University, Moscow, Russia
\textsuperscript{2}Institute of Mechanics, Lomonosov Moscow State University, Moscow, Russia

The effective equations for periodic composites with visco-elastic and elasto-plastic components are derived by use of methods developed in the Homogenization theory [1]. The theory is based on the assumption that the ratio $\varepsilon$ of the structure period to the global length scale of the problem is small. Slow and fast variables are introduced and asymptotic expansions on the small parameter $\varepsilon$ are used. In result one obtains averaged effective equations as well as equations to approximately determine local fields. For composites consisting of linearly elastic components in zero-order approximation with respect to $\varepsilon$ the effective medium is just a linearly elastic anisotropic medium with effective elastic moduli. Account of higher order terms in $\varepsilon$ yields models in which stresses depend on the higher order derivatives of displacements over time and space coordinates. In particular such models are considered in couple stress elasticity.

Effective equations describing large-scale processes in periodic composites with visco-elastic or elastic-plastic components qualitatively differ from the equations describing separate components. Two different forms of effective equations are possible. The first form corresponds to a medium with memory; stresses depend on the history of deformation. Another form corresponds to a medium with additional internal parameters and additional degrees of freedom connected with processes inside a periodicity cell [2].

The work was supported by Russian Foundation of basic research (11-01-00188a, 12-01-00960-a, and 12-08-01227a).

REFERENCES

PROGRESSIVE FAILURE ANALYSIS APPLIED TO E-GLASS FIBRE REINFORCED POLYMERS

B. Ellul and D. Camilleri

Dept. of Mechanical Engineering, University of Malta, Msida MSD 2080, Malta

Fibre reinforced composite materials are usually made up of fibres embedded in a bulk material strategically oriented in order to maximize the strength to weight ratio. Composite materials are designed to maximize the structural performance by utilizing the predominant material properties of each constituent phase. The amount, orientation, thickness and mechanical properties of the constituent lamina and phases can be adjusted to give rise to higher stiffness in particular orientations depending on the intended design and loading configuration. These smart materials are currently being used in a variety of industrial applications ranging from aerospace, marine, automotive, to civil and other applications such as entertainment and sports equipment.

Predicting the behaviour after initial failure enables us to design efficient structures that can safely withstand overloads that may occur. Numerical modelling gives the designer the ability to predict and analyse the mechanical response to various loading configurations including the complex post first ply failure behaviour and optimize the composite system to obtain a material with engineered structural performance. Failure of laminated composites is modelled by progressive failure where the load bearing capability is reduced incrementally until catastrophic failure is reached.

In this paper, we are presenting an implementation of the progressive failure algorithm (Fig. 1a) written in APDL and applied to fibre reinforced laminated polymeric composites. The results are corroborated with experimental ones found in literature such as illustrated in Fig. 1b. Furthermore, by exploiting the parametric design capabilities of APDL we show how the mechanical performance of a structure can predicted and improved.

Fig. 1. (a) Flow chart of the progressive failure algorithm. (b) Comparison of load-deflection curves between the proposed algorithm and the work carried out by Padhi et al. [1].

REFERENCES

EXPERIMENTAL AND THEORETICAL STUDY OF THE ENERGY ABSORBTION CAPABILITY OF FABRIC AND COMPOSITE ARMOUR MATERIALS

A. F. Ermolenko and E. F. Kharchenko

ARMOCOM, Center for Research, Design & Production of High Strength Polymer Composites, 141371, Khotkovo Moscow Distr., Russia
e-mail: metcom@tankcontainer.ru

Interaction of ballistic indenters with fabric or composite armour structures presents a complicated phenomenon that could be described with difficulty mathematically and investigated with use of structural models because as a rule mechanical characteristics and equations of state of armour package structural elements are unknown and their determination at high rate dynamic loading usually makes a big technical and scientific problem [1].

Elaboration of experimental methods for armour materials energy absorbing capability determination aiming materials selection and most rational placement in layered armour package is an actual problem. Not less actual is creation of physically valid and mathematically foreseeable models allowing to reveal main factors that determine materials capability to absorb kinetic energy of ballistic damaging agents.

In the work, dependencies of energy absorbed by armour material versus initial speed (kinetic energy) of ballistic indenter (energy spectrums) for aramid and polyethylene fabrics and composites were experimentally obtained and investigated. The experiments had been conducted on the basis of elaborated mechanical technic, using back media with known energy absorbing properties, and thermal one, using thermal imaging unit. A mathematical model of rigid ballistic indenter interaction with thin fabric or composite layer is offered and developed.

Experimental and theoretical investigations carried out in the work had shown that critical speed of ballistic agent (steel ball) at which perforation of the target material takes place (ballistic limit) within investigated speed interval from 200 till 800 m/s is fully determined by material specific fracture work at quasi-static tension. Material energy absorbing capability at speeds higher than ballistic limit is mainly determined by it’s rheological properties and practically doesn’t depend upon strength, ultimate strain or other properties at tension. The results obtained from theoretical studies using the mathematical model, offered and developed in the work demonstrate quite satisfactory correspondence with experimental data.

REFERENCES

1. Григорян В.А., Кобылкин И.Ф., Маринин В.М., Чистяков Е.Н. Материалы и защитные структуры для локального и индивидуального бронирования. Москва, Радио Софт, 2008.
ON THE USE OF NON-NEWTONIAN QUASI-VISCOUS LIQUID DISPERSE MEDIA IN FABRIC AND COMPOSITE ARMOUR STRUCTURES (LIQUID ARMOUR)

A. F. Ermolenko

ARMOCOM, Center for Research, Design & Production of High Strength Polymer Composites, 141371, Khotkovo Moscow Distr., Russia
e-mail: metcom@tankcontainer.ru

Many publications concerning development of the new materials for body armour of high efficiency in respect to ballistic protection, low mass and ergonomics appeared lately [1, 2] because materials traditionally used for body armour applications such as high strength aramid and polyethylene fabrics and composites on their basis are very close to exhausting of their kinetic energy absorbing resources and unable to ensure indispensable protection against ballistic damaging agents.

Attention is called to usage as new materials for ballistic applications of non-Newtonian quasi-viscous liquid and quasi-hard dispersions – polymers various nature filled with hard nano-size particles hardening at high rate of shear and recovering their quasi-liquid behavior after impact loading. Media with such properties are called shear thickening fluids (STF). Similar properties demonstrate some traditional polymer materials, like rubbers, filled with hard particles. Armour structures consisting of traditional aramid fabrics impregnated with STF are called “liquid armour”.

In the work methods of obtaining, testing, properties description of STF in vitro and in armour structures subjected to ballistic loading are surveyed and critically analyzed. It is shown that quasi-viscous behavior of STF is caused by dilatancy – phenomenon known in theory of non Newtonian fluids and in practice of processing polymers filled with small hard particles having dimensions from 10 to 500 nanometers.

Analysis given in the work showed that elaboration of polymer compositions having mechanical characteristics of structural materials and containing inclusions that demonstrate quasi-viscous properties at local dynamic impact loading would be most promising for creation of new composite body armour materials capable to protect against ballistic damages and injuries and being practically applicable.

REFERENCES

ZINC OXIDE (ZnO), MAGNESIUM HYDROXIDE [Mg(OH)₂] AND CALCIUM CARBONATE (CaCO₃) NANO-POWDER-FILLED HDPE POLYMER COMPOSITES: MECHANICAL, THERMAL AND MORPHOLOGICAL PROPERTIES

S. Ersoy¹ and M. Taşdemir²

¹Marmara University, Technical Education Faculty, Dep. of Mechatronics Edu., Goztepe, Istanbul, 34722, Turkey
²Marmara University Technology Faculty, Department of Metallurgical and Materials Engineering, Istanbul 34722, Turkey
e-mail: munir@marmara.edu.tr

Polymer nanocomposites represent a new alternative to conventionally filled polymers. Because of their nanometer sizes, filler dispersion nanocomposites exhibit markedly improved properties when compared to the pure polymers or their traditional composites. These include increased modulus and strength, outstanding barrier properties, improved solvent and heat resistance and decreased flammability.

In this study, mechanical, thermal and morphological properties of the high density polyethylene (HDPE) composites filled with nano zinc oxide ZnO), magnesium hydroxide [Mg(OH)₂] and calcium carbonate (CaCO₃) were investigated. The structure and properties of the composites are characterized using a scanning electron microscopy (SEM) and Energy dispersive X-ray spectroscopy (EDS). Furthermore, HDPE composites were subjected to examinations to obtain their tensile strengths, yield strengths, elasticity modulus, % elongation, Izod impact strength, hardness, wear strengths, heat deflection temperature (HDT), Vicat softening point and melt flow index (MFI).
THERMAL BEHAVIOR OF COMPOSITES CONTAINING CARBON FIBERS OR CARBON NANOTUBES UNDER CRYOGENIC THERMAL CYCLING

L. E. Evseeva and S. A. Tanaeva

Heat & Mass Transfer Institute, National Academy of Sciences of Belarus 220072 Minsk, Belarus, e-mail: evseeva@itmo.by

Epoxy reinforced composites are used in many cryogenic and aerospace applications. Nano-reinforcements, as opposed to traditional reinforcements, have been shown to improve the mechanical and thermal properties at much lower filler-concentration. Advanced composite materials must be able to survive in a cryogenic environment without apparently generating any structural degradation. One of the most important problems is to provide the cryogenic stability at numerous repeated deep cooling and heating (thermal cycles). A thorough understanding of their thermal behavior at low temperatures and under thermal cycling is necessary.

Thermal physical properties such as thermal conductivity and specific heat are very informative characteristics about structure changes in composite materials under different external effects. Earlier thermophysical properties of glass fiber and carbon fiber reinforced composites as well as thermal properties of polymer mineral particle-filled composites were investigated [1, 2]. It was shown that thermal cycling results in the essential, sometimes anomalous, changing of thermal properties, due to the destruction of the material under the thermal cyclic loading. Powder and particle fillers improve the resistance of polymer composites to thermal cyclic loading. Use of carbon nanotubes (CNTs) reinforced polymer matrix nanocomposites is regarded as a new means to overcome the disadvantage of the polymeric materials against such a destructive exposure as an alternating heat impact.

In the present study, we focus our attention on the investigation of low temperatures and cryogenic thermal cycling influence on the thermal conductivity of epoxy/carbon nanotube nanocomposites and of epoxy composites reinforced by discrete short carbon fibers and a comparison their behavior to those of CFRP. Some tests on the thermal cyclic loading with the amplitude of 77.3K ÷ 403K were performed. The sample was placed into the liquid nitrogen during 10 minutes and then replaced to the air-oven (20 min). The number of thermal cycles was variable. Thermal conductivity and specific heat of the epoxy composites have been studied. Measurements were carried out using a monotonous regime method, in the temperature range from –150 °C to 150 °C. It was shown that multiple thermal cycling results in a significant decrease of unidirectional CFRPs thermal conductivity. The chaotic reinforcement by discrete short CFs slightly enhances the cryogenic stability of composites. But CNT-loading greatly increases both the thermal conductivity of epoxy composite and its cryogenic stability.

REFERENCES

During braking, the brake pad material has a high temperature gradient due to the friction induced heat flux in the surface between rotor and disc. Furthermore, conventional automotive brake friction materials are composites bonded with a phenolic resin reinforced with metallic or non-metallic fibers, and thus they contain a distribution of small pores, which can retain moisture at ambient conditions. Dealing with the behavior of these materials, relation between heat and moisture field can’t be neglected; the problem has to be handled coupled, because the Soret and Dufour effects [1].

The influence of the moisture and the water spray (e.g.: operation in a rainy or humid environment) on the coefficient of friction was documented in the past. According to these investigations in the wet sliding conditions there is a significant reduction in the friction coefficient compared to the dry conditions, which influences the safety of the vehicle.

In relation of moisture, Lee et al. [2] showed by a block-on-disc brake testing machine that weight changes of lining material caused by moisture adsorption is to be similar in magnitude to the weight change caused by wear. Therefore heat conduction and moisture diffusion has an important influence on wear test results. But calculations of the moisture adsorption and heat conduction problem of these materials have not been quantitatively reported in the context of different braking conditions and overnight period.

This study discusses the mathematical model of the cross-coupled heat and moisture transport of brake lining materials with initially and boundary conditions (Fig. 1).

![Fig. 1. Thermal and moisture processes in a brake lining material.](image)

**REFERENCES**

ANALYSIS OF THE MECHANICAL PROPERTIES OF NANOFILLED EPOXY COMPOSITES

J. A. M. Ferreira¹, A. M. S. Pereira¹, P. N. B. Reis², and J. D. M. Costa¹

¹CEMUC, Department of Mechanical Engineering, University of Coimbra, Rua Luís Reis Santos, 3030-788, Coimbra, Portugal
²Depart. of Electromechanical Engineering, University of Beira Interior, Covilhã, Portugal

Nanoclay filling of polymer matrices is a feasible way to increase the mechanical properties in comparison with net matrix. The key factor thought to get this increase on the mechanical properties of the material is the degree of dispersion and exfoliation of the clay material into the epoxy matrix. This paper studies the influence of nanoclay content and water uptake on the mechanical properties for epoxy nanoclay filled composites. The specimens were manufactured using the epoxy resin SR 1500 and the hardener SD 2503 and the commercially Nanomer I30 E nanoclay.

In spite XRD analysis suggest clay exfoliation tensile strength and fracture toughness decreases with the nanoclay content. Young’s Modulus increases only up to 3 wt. % of filler as can be showed in Fig. 1. Water absorption increased with nanoclay filler content. The energy absorbed in impact tests decreases with the increase of clays into the matrix on dry specimens, but increases substantially for the samples after immersed in water.

![Fig. 1. Apparent modulus of elasticity versus nanoclay content.](image-url)
MODERN METHODS OF PROGRESSIVE FAILURE ANALYSIS OF COMPOSITE STRUCTURES USING MSC.SOFTWARE

L. Firsov, R. Gadelev, A. Leonov, and A. Safonov

SCA, Sukhoi Civil Aircraft, Russia

The report is devoted to the problem of progressive composite structure with global hub by the example of rectangular sample with the hole, in the ratio of the diameter to the sample width 1:2.

The developed software system, which is the add-in to the finite element package MSC.PATRAN/NASTRAN described in the report. The software system carries out the analysis of progressive failure of composite materials. There is given a comparative analysis of the existing degradation models of composite materials. There is suggested a flow chart for designing of proper progressive failures models from the existing criteria set of strength, model of properties degradation and choice of stress increment.

The described software package analyses input and output files of the “solver” of MSC.NASTRAN. The problem of composite structure static strength for determination of the initial stress strain behaviour is solved on the opening stage. The automotive iterative procedure of the analysis is started up then. Each stage of the procedure increases the external load and calculates actual stress in composite materials. Then, criteria of strength are applied to each layer of composite materials for analysis of possible failure of fiber, matrix or adhesive layer. After determination of failure parameters, the reduction of stiffness properties of the damaged areas of composite material in accordance with mode of failure is executed. The computation of updated reduced characteristics of the package is carried out and computation files for finite element “solver” for the next iteration are formed.

Module for output of different calculation results is realized: increase of failure area at each iteration, monitoring of failure type (fiber, matrix), the output of deformations, stresses and minimal factors of safety is performed.

There are given the results of tensioning analysis of the sample with the hole.
PROCESSING–STRUCTURE–PROPERTY RELATIONSHIPS OF THERMOPLASTIC NANOCOMPOSITES USED IN FRICION AND WEAR APPLICATIONS

K. Friedrich1,2, N. Knör3, and A. A. Almajid2

1Institute for Composite Materials (IVW GmbH), Technical University of Kaiserslautern, 67663 Kaiserslautern, Germany
2CEREM, King Saud University, Riyadh, Saudi Arabia
3HOFFMANN MINERAL GmbH, 86633 Neuburg (Donau), Germany

In recent years the consumption of polymer based composites in many engineering fields where friction and wear are critical issues has increased enormously. One way to further improve the tribological performance of these materials is to incorporate, besides the classical tribo-fillers such as short carbon fibers and lubricating graphite flakes, additional ceramic nanoparticles into the polymeric matrix. In general, the implementation of nano-scaled fillers to enhance polymeric properties seems to be promising and, therefore, it is of high interest in research and industry. However, due to large surface area and high adhesion forces, nanoparticles are not existent as single particles but as agglomerations or aggregations. For achieving the desired material improvements it is necessary to split-up these agglomerations and to distribute them as single particles within the polymeric matrix.

Twin screw extrusion is one of the most commonly used techniques for implementation of fillers and additives into polymers. Therefore, this method is used within this work to generate improved polyamide 66- and polyetheretherketone-matrix composites via an incorporation of titanium dioxide particles (15 and 300 nm).

In a first step, processing parameters, such as throughput and screw speed, as well as process management and thus their influence on material properties were examined. The specific energy input is crucial for the de-agglomeration of nanoparticles. It showed, however, only small dependencies on the throughput and screw speed. After the insertion of particles it led to almost no changes in the degree of de-agglomeration and no improvements in the mechanical properties. Process guiding was divided into multi-pass and single-pass extrusion. Production of a highly filled masterbatch, its multiple extrusion and dilution resulted in a very good de-agglomeration and highly enhanced material performance. Via simulation of the twin screw extrusion process, it could be proved that the existence of non-molten granulates inside the extrusion zones causes a melt/ nanoparticles/ solid-friction, which seems to be the reason for well dispersed particles. Modification of the single-pass extrusion process reached almost the degree of de-agglomeration of the multi-pass extrusion process, but at the end, the materials gained by multi-pass extrusion processing exhibited the highest material improvements.

In a second step, a variation of particle sizes and content was performed. 15 nm particles showed significantly better mechanical property improvements than 300 nm particles. The effectiveness of the 15 nm particle was better for polyetheretherketone than for polyamide 66. Enhancements in stiffness, strength, and toughness could be achieved. Scanning electron microscopy confirmed these results. Finally, a few examples are shown in which these kinds of nanocomposites are used as real materials for friction and wear elements in various industrial applications.
A test campaign was carried out to investigate the behaviour of co-bonded structural joints on graphite-epoxy specimens. Different specimens have been manufactured to investigate static and fatigue behaviour, as well as delamination size after impact and damage tolerance characteristics. High Load Transfer (HLT) joints subjected to uniaxial tension loading as well as Bonded Flange Specimens loaded in four point bending to produce mixed mode compression loading were tested (Fig. 1). Specimens without 3-D reinforcement are co-bonded, adding a film of adhesive in the overlap area. Other specimens contained a reinforcement based on the insertion of spiked thin metal sheets between the co-bonded laminates, which allowed one to obtain a more predictable and hindered failure with respect to the solely adhesive structural bonding. This solution can provide the means to allow composite bonded joints to be certified. Today’s Aeronautic certification rules [1, 2] bring to the following possible approaches for adhesive bonded joints: (a) Repeatable and reliable non-destructive inspection techniques that must be established to ensure the strength of each joint (currently not available); (b) Full single part testing of bonded joints (not practical); (c) Disbonds of joint greater than the maximum critical disbonding to be prevented by design features (e.g. chicken fasteners). Test results on single lap specimens with metallic spikes, have shown an improvement in the static strength up to 25%. The crack bridging mechanisms are capable to endure longer cracks before ultimate failure. Metallic spikes represent an enhanced damage tolerance characteristic under fatigue loading. Cycling load at stress level, which typically brings to failure the co-bonded joint after a number of cycles within the design service goal, resulted run-out (> 3 million cycles) when metallic spikes are used.

REFERENCES

PREPARATION AND PROPERTIES OF NANOCOMPOSITES FROM POLYURETHANE REINFORCED WITH MONTMORILLONITE

S. Gaidukov\textsuperscript{1}, K. Gromilova\textsuperscript{1}, R. D. Maksimov\textsuperscript{2}, V. Tupureina\textsuperscript{1}, U. Cabulis\textsuperscript{3}, and A. Fridrihsone\textsuperscript{3}

\textsuperscript{1}Riga Technical university, Institute of Polymer materials, Azenes Str.14/24, Riga, LV 1048, Latvia, sergeis@ktf.rtu.lv
\textsuperscript{2}Institute of Polymer Mechanics, University of Latvia, Aizkraukles Str. 23, LV 1006, Riga, Latvia
\textsuperscript{3}Latvian State Institute of Wood Chemistry, Dzerbenes Str. 27 Riga, LV-1006, Latvia

In the last years, there are many investigations on the development of methods for preparation of polymer nanocomposites containing nanosized particles of montmorillonite as filler and the characterisation of their properties. Many different polymers for nanocomposite preparation can be used [1].

This study is a continuation of the investigations presented in [2, 3], which were devoted to intercalation of organically modified montmorillonite (organomontmorillonite) nanoparticles in melt [2] and solution [3]. Current research is dedicated to preparation of polymer nanocomposites formed through step-growth polymerization, by reacting two monomers in the presence of nanoparticles.

We report on the polymer nanocomposites in situ preparation by synthesis of polyurethane from polyol and polysisocyanate with addition of montmorillonite. Organically modified montmorillonite solution in organic solvent is used to obtain homogeneous dispersion of elementary montmorillonite particles in the polymer matrix. Five different compositions with organomontmorillonite content from 0 to 10 wt.% are prepared and tested.

X-ray diffraction analysis and differential scanning calorimetric measurements are performed to characterise structure features and component mutual interaction of prepared nanocomposites.

Observed, that nanoparticle addition strongly influences material tensile properties: stress-strain curves, elasticity, tensile strength, and ultimate elongation. Temperature of degradation and weight losses are evaluated from thermograms of thermal gravimetric analysis.

Acknowledgement. The study was supported by the ERAF Nr. 2010/0214/2DP/2.1.1.1.0/10/APIA/VIAA/054 Development of Volatile Organic Compounds Non-Containing Sprayable Polyurethane Coatings from Renewable Raw Materials.

REFERENCES

ASSESSMENT OF THE FATIGUE LIFE OF A TOWER BY USING A REAL-TIME LOADING HISTORY

L. Gaile¹ and I. Radinsh²

¹Department of Structural Engineering, Riga Technical University, LV-1048, Riga, Latvia
²Department of Structural Analysis, Riga Technical University LV-1048, Riga, Latvia

High and slender sightseeing towers are subjected not only to a wind caused vibrations but also to a human’s caused vibrations. If the natural frequency of the structure is close to the frequency of the human pacing, then human and structure’s interaction should be considered in the tower design. The main component of the sightseeing tower is stairs and human movement on them generates significant longitudinal and transverse force components that cause sightseeing tower’s torsional and transversal vibrations. Additionally there could be a resonant built up problem that causes increase of the service stress range.

There were experimentally measured vibrations and obtained a real time history of the eccentric, 36 m high steel structure sightseeing tower in Jurmala, Latvia. Figure 1. shows the tower tip movement acceleration path in 20 sec time.

The complex loading history fatigue life assessment usually is performed by using rainflow method when counting an irregular stress – time history. In cases, where is a need for the modal parameter estimation, it would be very convenient to use frequency domain fatigue approach.

There was performed fatigue life assessment using experimental data of the tower’s most important connection with both above mentioned approaches and given comparison. It is assessed service life expectancy for the steel double core sightseeing tower in Dzintari.

Fig. 1. Tower tip acceleration path in 20sec time.
Polylactic acid (PLA) is a thermoplastic aliphatic polyester derived from renewable sources such as corn starch and it is able to biodegrade hydrolytically and enzymatically. However, its poor thermal and mechanical resistance and limited barrier properties limits its access to those industrial sectors, where biodegradability is required. PLA is used as biocompatible polymer for applications in biomedicine having also a great potential for applications in agriculture and biodegradable consumer items [1].

The aim of the present work is the preparation of a green composite, specifically a wood-plastic composite based on PLA, and studying the effect of wood flour fillers on polylactic acid matrix at different weight fractions. Experimental techniques including Scanning Electron Microscopy (SEM), Differential Scanning Calorimetry (DSC), Dynamic Mechanical Analysis (DMA), and tensile measurements were employed to analyze the degree of thermomechanical enhancement of PLA due to wood flour fillers, the fillers dispersion on the PLA matrix and the influence of wood flour content.

REFERENCES
FORMATION OF INTRALAMINAR CRACKS IS THE MAIN REASON FOR DEGRADATION OF THERMOELASTIC PROPERTIES IN COMPOSITE LAMINATES. THIS CRACKING CAN BE A RESULT OF MECHANICAL AND/OR THERMAL LOADING. THERE ARE SEVERAL STUDIES FOCUSING ON THE REDUCTION OF ELASTIC MODULUS IN DAMAGED LAMINATES [1, 2]. HOWEVER, THE REDUCTION OF THE IN-PLANE SHEAR MODULUS WITH RESPECT TO TRANSVERSE CRACKING HAS BEEN CONSIDERED IN ONLY FEW CASES. ACCEPTABLE VALUES OF THIS REDUCTION CAN BE OBTAINED BY USING FINITE ELEMENT MODELS. HOWEVER, SIMPLE ANALYTICAL MODELS ARE EASIER TO APPLY TO ANALYZE TRENDS. HASHIN [1] Suggested A MODEL IN WHICH THE STRESS DISTRIBUTION IS BASED ON MINIMIZATION OF THE COMPLEMENTARY ENERGY. HOWEVER, THIS MODEL LACKS IN ACCURACY, AS IT ASSUMES LINEAR OUT-OF-PLANE SHEAR STRESS DISTRIBUTION WITH RESPECT TO SAMPLE’S THICKNESS. IN THE CURRENT WORK MODEL HAS BEEN DEVELOPED THAT IS APPLICABLE FOR TWO STACKING SEQUENCES OF COMPOSITE LAMINATES; [Sn/90n]s AND [90n/Sn]s, WHERE S IS CONSIDERED TO BE A SUBLAMINATE WITH KNOWN ELASTIC PROPERTIES. FIRST, THE STRESS DISTRIBUTION IS ANALYZED USING SHAPE FUNCTIONS OF DIFFERENT COMPLEXITIES. THEN THE RESPECTIVE VALUES OF THE SHEAR MODULUS ARE CALCULATED AND COMPARED WITH FINITE ELEMENT RESULTS AND WITH THE RESULTS OBTAINED BY HASHIN.

REFERENCE

MECHANICAL PROPERTIES OF EPOXY AND AN EPOXY-BASED CFRP FILLED WITH CARBON NANOTUBES

T. Glaskova¹, A. Aniskevich¹, M. Zarrelli², A. Martone², and M. Giordano²

¹Institute of Polymer Mechanics, University of Latvia, Riga, LV-1006, Latvia
²Institute for Composite and Biomedical Materials, National Research Council, Portici (NA), Italy

The effect of carbon nanotubes (CNTs) is widely investigated in the last years for the modification of the polymer resin used in carbon fibre-reinforced plastics (CFRPs) which can improve the adhesion between epoxy and carbon fibers and as result leads to enhanced mechanical, electrical, magnetic, and other properties. However, the formation of nanoparticles’ agglomerates within a polymer system surely influences the final nanocomposite (NC) performance such as strength, stiffness, fracture toughness, electrical/thermal conductivity, transparency etc.

The aim of this work is to determine the effect of CNTs on elastic and viscoelastic properties of epoxy resin used in CFRP. In order to increase the rate of relaxation processes moisture saturation level has been achieved prior to mechanical testing of the composite material.

The multiwall CNTs with average diameter 140 nm and average length 7 μm used as filler were provided by Aldrich. A monocomponent epoxy resin RTM6 was provided by Hexcel. Two different compositions of RTM6 resin and CNT (0 and 1 wt. %) as is and for CFRP were prepared by ultrasonication method for 60 min at power 36 W and temperature \( T = 120^\circ C \), degassing for 30 min at \( T = 80^\circ C \), curing for 1h at \( T = 160^\circ C \) and post-curing for 2 h at \( T = 180^\circ C \). Neat and CNT containing CFRP specimens [0/45/90/45]₂ were prepared by resin transfer molding at \( T = 90^\circ C \), curing for 1h at \( T = 160^\circ C \) and post-curing for 2 h at \( T = 180^\circ C \).

In order to study the peculiarities of moisture sorption for specimens of RTM6 and CFRP with different content of CNTs (0 and 1 wt. %) the sorption experiments were performed in atmosphere with relative humidity 98% at room temperature until the saturation (app. 18 months). Three point bending tests were carried out for initial and moistened NC and CFRP specimens at room temperature in quasistatic and cyclic creep regimes. Four cycles of gradually increasing stress equal to app. 25, 50, 75, and 90% of bending strength were used for loading during 30 min followed by 30 min of unloading.

The results obtained for NC resulted in increase of bending modulus by 11%, reduction of strain at break and bending strength by 28 and 20%, accordingly, in relation to CNT content. CFRP with 1% of CNTs showed slight improvement in bending modulus (by 9%) and strength (16%) in comparison with the neat CFRP. The sorption and swelling processes in CFRP resulted in increase of diffusion coefficient by 50% and coefficient of swelling by 27%, decrease of equilibrium moisture content by 15% in comparison with the neat CFRP.
OPTIMAL DESIGN OF COMPOSITE WING BOX STIFFENED PANELS
PROVIDING STRENGTH AND STABILITY

S. Gluhih$^1$, O. Mitrofanov$^2$, and A. Sorokin$^3$

$^1$Institute of Materials and Structures, Riga Technical University, Riga, Latvia
$^2$“Sukhoi civil aircraft” closed joint-stock company (“SCAC” CJSC), Moscow, Russia
$^3$AVIATEST ( LNK group ), Riga, Latvia

One of peculiarities of stiffened panels (SP) design for aircraft composite wing with minimum weight is the necessity of taking into account possibility of different buckling failures with ultimate loads. Besides while designing SP, it is necessary to take into account various modes of composite material failure including those originating from transverse shear stress influence.

Composite SP design methods developed on the basis of equistability principal are offered in this work. Different variants of loading (including combined shear and compression loading) are taking into account. Analytical dependences of SP thickness vs load allowing one to estimate different design concepts examined at an early stage of design and to compare different types of SP are obtained.

Researches of SP element optimal reinforcement in case of strict stability limits have been performed on the basis of developed methods. Recommendations on several types of SP optimal reinforcement are given. Research results complement conclusions to which task of optimal reinforcement with static strength strict restrictions draw.

Offered compressed composite SP design methods are modified taking into account traditional coefficients of reduction application which take into account possible local skin buckling. Analytical dependences allowing one to define coefficients of reduction for composite compressed panels including those taking into account transverse shear stress influence have been obtained on the basis of geometrically nonlinear relationships of orthotropic panels. Stress distribution peculiarities in case of buckling relative to composite thick panels are shown. You can also find an estimation of bending stress influence.

Recommendations on allowable stress choice for wing box upper SP optimal parameters definition in case of static strength and stability restrictions have been developed on the basis of performed researches.

89
POSTBUCKLING-STATE-ASSISTED DESIGN OF COMPOSITE DEVICE PANELS
BY TAKING INTO ACCOUNT THE FATIGUE LIFE AND RESIDUAL
STRENGTH BOUNDARY CONDITIONS

S. Gluhii1, O. Mitrofanov2, and A. Sorokin3

1Institute of Materials and Structures, Riga Technical University, Riga, Latvia
2“Sukhoi civil aircraft” closed joint-stock company (“SCAC” CJSC), Russia, Moscow
3AVIATEST (LNK group), Riga, Latvia

In the case of design of composite wing high-lift device thin skins, buckling is permitted at the loads close to the proof ones. This project suggests engineering approach to postbuckling state assisted design of composite thin-walled devices taking into account life time boundary conditions. Fatigue life and residual strength boundary conditions in the case of damages, such as dents, have been examined. Boundary conditions with specified barely visible impact damages in case of ultimate loading and with visible impact damages in case of increased limit loading have been taken into account.

Postbuckling state assisted design complex methodology for thin panels based on analytic solutions of geometrically non-linear problems has been suggested. It is also supplemented with fatigue life and residual strength boundary conditions.

Analytic dependences have been obtained which make it possible to calculate minimal composite panel thickness with damages of specified type and with given device dimensions, known potentially critical areas, restricted damages (dents), known composite design performances and given loading. Panels combined loading cases taking into account thermal effect have been examined.

Developed methodology may be used at early stages of composite thin-walled devices design in order to define skin minimal thicknesses taking into account specified damages (dents).
IDENTIFICATION OF THE OUTER-LAYER MODULUS OF A TWO LAYER POLYMER CYLINDRICAL SHELL

S. Gluhih, A. Kovalovs, and A. Chate

Institute of Materials and Structures, Riga Technical University, Kalku St. 1, LV-1658, Riga, Latvia

The purpose of the present investigation is to solve a compression problem of thin cylindrical polymer shell with two layers by two planes in the finite element program ANSYS. The cylindrical shell consists of two layers with different elastic modulus. The inner layer (bandage) of the cylindrical shell is made from a rigid polymeric material with relatively high Young’s modulus. The outer layer is made from a softer. The average radius $R$, the length $L$, the Young’s modulus of the inner layer $E_1$ and the thickness of both layers $t_1$ and $t_2$ of the cylindrical shell are assumed to be known. The parameter to be identified is the elastic modulus of the outer layer $E_2$.

For the identification of the elastic modulus of the outer layer $E_2$ the TWCS method (Method for the Identification of the Elastic Properties of Polymer Materials by Using Thin-Walled Cylindrical Specimens) is considered.

The finite element model is built by using SHELL181 element which allows multi-layer properties and has the form of a quarter of a circular ring owing to symmetry. The boundary conditions correspond to the symmetry conditions. The deformation of a thin polymer shells is characterized by great displacements and relatively low elastic deformations in a large range of movement of parallel planes.

According to the above mentioned method at first, the so-called reduced elastic modulus $E_{priv}$ (modulus of inelastic buckling) is determined from the compression experiment of a cylindrical shell. The cylindrical shell is assumed to be single-layered with total thickness $t$. Then the step-down ratio for the elastic modulus $E_1/E_{priv}$ is introduced.

The series of calculations of the cylindrical shell with different elastic modulus of the outer layer are carried out. Obtained results are tabulated and then on the basis of these tables the graph of the dependence of the relative Young’s modulus $E_1/E_{priv}$ from the logarithm of the ratio of the elastic modulus of layers $lg(E_1/E_2)$ is constructed.

Also, it was necessary to find out the influence of the geometrical parameter $R/t$ on the elastic modulus of layers. On this reason the cylindrical shells of relative radius $R/t$ were considered. Influence of this parameter appeared to be extremely small - within 0.3 %.

Thus, the obtained graph of the dependence of the elastic modulus of layers from the ratio of the thicknesses of layers is true in the considered range $R/t$, which is the solution of the problem.
DESIGN OF CARBON-NANOTUBE-REINFORCED ALUMINUM-MATRIX COMPOSITES

J.-K. Gomon¹, L. Kommel¹, L. Kollo¹, J. Majak², R. Metsvahi¹, and M. Mihhaltsenkov¹

¹Department of Materials Engineering, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia
²Department of Machinery, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia

Equal Channel Angular Pressing (ECAP) of metallic materials is an effective method for introducing high strains and microstructure refinement by simple shear. The ECAP processing has been extensively investigated for bulk aluminium alloys [1]. It is shown to be especially promising for age-hardenable alloys, whereas the strength properties of ECAP-treated non-age-hardenable alloys exhibit only minor improvements compared to well established cold rolling [2].

In the current study the new multi-pass angular pressing (MPAP) technique with stepwise decreasing cross-sections of three channels is employed. As result, the back-pressure formed automatically as the channel cross-section area decrease, respectively. According to this method the powder compacts were enclosed in a metal capsule and extruded as bulk metal. Compared to conventional ECAP the von Mises strain was increased up to two at one pass.

The mechanical properties of ECAP materials are mainly influenced by number of passes, processing temperature and the different routes (conventionally defined as A, Bc and C routes). These variables are considered as design variables.

In order to predict the mechanical properties of the aluminum matrix composite the mathematical models are developed by employing artificial neural network (ANN). A feed-forward neural network with one hidden layer and Levenberg-Marquardt training algorithm are used. Further the ANN models developed are used as objective functions for the evolutionary multi-objective optimization. The optimal solutions are analysed and sensitivity analysis is performed. The optimised processing parameters for increased ductility and strength of commercial purity aluminium will be transferred to compacting of Al-CNT composites.

The obtained results show that depending on cumulative strain increase as well as heat treatment temperature increase the microhardness of binder phase was increased which leads to the improvement of mechanical and tribological properties of the composite.

REFERENCES


ANALYSIS OF HYBRID COMPOSITE CABLE FOR PRESTRESSED SUSPENSION BRIDGE

V. Goremikins, K. Rocens, and D. Serdjuks
Dept. of Structural Engineering, Riga Technical University, Latvia

Prestressed suspension bridge is a type of structures which allows covering long spans due to rational use of structural materials. Prestressing of suspension bridge allows to minimize kinematic displacements and makes possible not to use cantlage.

The stress distribution by the length of the main load carrying cable of suspension bridge is non-uniform. Equalization of stresses by the length of the cable open possibility to increase degree of material usage. The effects of stress equalization by the length of the cable can be achieved with the using of cable with variable by it length cross-section.

The prestressed suspension bridge with main span equal to 200 m was considered as an object of investigation (Fig.1). Hybrid composite cable on the base of steel and CFRP with variable by it length cross-section of steel component is considered as a main load-carrying structure of the prestressed suspension bridge. Using of CFRP component allows increasing specific strength of the cable and decrease total dead weight of load-carrying structure. The hybrid composite cable was divided into the section with the length equal to the distances between the suspensions.

The considered prestressed suspension bridge was investigated by the FEM software ANSYS 12.

Rational cross-section of steel components of hybrid composite cable was determined for each section. Influence of the effect of stress equalization by the length of the cable on the materials consumption and displacements of prestressed suspension bridge was investigated.

Fig.1. Prestressed suspension bridge.

REFERENCES

QUASISTATIC AND DYNAMIC MECHANICAL PROPERTIES OF POLYOXYMETHYLENE AND ETHYLENE-OCTENE COPOLYMER COMPOSITES

A. Grigaloviča¹, M. Bartule¹, J. Zicans¹, Ch. Berger², and H.-P. Heim²

¹Institute of Polymer Materials, Riga Technical University, Azenes street 14/24, LV-1048 Riga, Latvia
²Institut für Werkstofftechnik - Kunststofftechnik, University of Kassel, Mönchebergstr 3, 34109 Kassel, Germany

Nowadays in different industries there is a demand for new functional materials with advanced properties. Polymers commonly increasingly are used as a direct replacement for metals because they have good stiffness, dimensional stability and also they are corrosion resistant, lightweight and can be easily processed in different shapes. One of the most important engineering polymers is polyoxymethylene (POM). It has good mechanical properties, but it shows some notch sensitivity and poor impact strength, especially in low temperature range. And these factors limit POM exploitation. To improve impact strength in wide temperature diapason as well as other exploitations properties POM has to be modified with other polymers, such as elastomers and rubbers.

In this work,. POM co-polymers POM300, POM900 with different viscosities were blended with ethylene- octane co-polymers EOC8200 and EOC8540 with various alpha-octene contents- 38% (EOC38) and 17% (EOC17). The composites were obtained by using twin- screw extruder. Both structural (fracture morphology, crystallinity etc) and exploitation properties (stress-strain characteristics, impact behavior etc) of various POM/EOC compositions were investigated.

Results of the investigations of the structural properties of POM/EOC composites demonstrate that POM/EOC blends are heterogeneous by it nature and are characterized with broad phase transition region between 30-70 wt. of POM. In this region intrinsic incompatibility between the components of the blends is expressed to greater extent, as it is demonstrated by dynamic and morphological investigations. In general, considering melt viscosities of POM and EOC, compositions with higher elastomer content in the phase transition region are characterized with finer distribution of minor phase in the continuous matrix. However, it has been determined that overall mechanical properties of POM/EOC blends depend not only from morphology, but also other structural features, such as crystallinity degree and spherulitic ordering.

Tensile and flexural elastic properties as well as impact strength of various POM/EOC compositions were investigated at different temperatures, i.e., below and above of glass transition of the neat components. The investigations of mechanical properties demonstrate that at small EOC content (up to 30%) increase of the impact strength of POM/EOC composites is observed. As expected, greater increase in impact strength was observed for the compositions with EOC38, because of its higher alpha-octene content. Compositions with EOC17, however, showed higher elastic modulus and strength.
INVESTIGATION OF BOND BETWEEN GFRP BARS AND CONCRETE

E. Gudonis¹, A. Weber², V. Gribniak¹,³, R. Jakubovskis¹, and G. Kaklauskas¹

¹Department of Bridges and Special Structures, Vilnius Gediminas Technical University (VGTU), Vilnius 10223, Lithuania
²Schöck Bauteile Ltd, Baden-Baden 76534, Germany
³Department of Strength of Materials, VGTU, Lithuania

Fibre reinforced polymers (FRPs) are considered to be a promising alternative to usual steel reinforcement, especially if structure is subjected to aggressive environment. With superior durability, common types of FRP materials have a tensile strength up to 5-6 times higher than structural steel. However, the relatively low elastic modulus of FRP bars (in respect to the steel) generally leads to the larger deformation of FRP-reinforced structural elements. Therefore, the serviceability limit states (mostly limitation of deformations) often become the governing criterion for design of FRP-reinforced concrete elements.

Deformation prediction results are strongly dependent on the assumed tension-stiffening model [1]. Tension-stiffening is closely related to bond between concrete and reinforcing bars. The bond of steel reinforcement is well-understood and generally referred as “good” when ribbed bars are used. Meanwhile, bond of FRP reinforcement may not be adequate and it is mostly dependant on the surface treatment of the bars.

This manuscript presents results of experimental and numerical study of bond between glass fibre reinforced polymer (GFRP) Schöck ComBAR bars and concrete. The comprehensive experimental program consisted of the pull-out and bending bond tests as well as the beam tests schematically shown in Fig. 1. The obtained bond stress-slip relationships from pull-out and bending bond tests were used in the finite element software ATENA for simulating the experimental beams.

Fig. 1. Specimens for bond investigation: a) bending test; b) pull-out test; c) beam test.

REFERENCES

INTERCONVERSION OF VARIATIONAL EQUATIONS IN A COMPARATIVE FUNCTIONAL ANALYSIS OF SPECIFIED MODELS OF LAYERED PLATES

O. G. Gurtovy

National University of Water Management and Natural Resources Uses, Soborna St. No.11 Rivne, 33000, Ukraine

The variational approach to the comparative analysis of the specified models of curving of plates with orthotropic layers is offered. Models take into account strains of transverse shear and transverse compression.

The approach assumes interconversions of one in another of the variational equations \( \delta F_i = 0, \ (i = 1, 2) \) [1]. These equations answer conditions of a stationarity of the Lagrange functionals \( F_i \) of two compared models \( M_i \). Thus, such side conditions \( f_m = 0; \ m \geq 1 \) (links between varied functions) with indefinite factors of Lagrange \( \lambda_m \) are applied. These links establish mathematical identity of recording of both functionals.

Affirms, that if both transformations \( \delta F_i + \delta (\lambda_m f_m) = 0 \Rightarrow \delta F_j = 0 \ (i \neq j) \) are possible, then functionals \( F_i \) and models \( M_i \) are identical. If one transformation, for example only \( \delta F_1 = 0 \) is possible in \( \delta F_2 = 0 \), then model \( M_1 \) and a functional \( F_1 \) more exact and common, than \( M_2 \) and \( F_2 \). If inverse transformation is possible in that specific case \( \delta F_2 + \delta (\lambda_m f_m) + \delta (\lambda f_k) = 0 \Rightarrow \delta F_1 = 0 \), where \( f_k = 0 \) is a function space of states of a condition (in addition to \( f_m = 0 \)) models \( M_i \) are identical only in this special case. Conditions \( f_k = 0 \) can be a separate case of boundary conditions, etc.

The offered approach is used to selection of more common and exact from two known models of plates high [2], but the different order of approximation of factors of transverse shear and compression in stress-strain state. Recommendations to their application are given.

REFERENCES

1. Гуртовый А. Г. Расчет неоднородных пластин из ортотропных слоев на основе уточненных моделей// Автореферат дисс. ... канд.техн.наук.— Киев: КАДИ.,— 20с.-1984.
2. Гуртовый А. Г., Пискунов В. Г. О сравнительном анализе уточненных моделей слоистых ортотропных пластин// Прикл. механика.— Т.34, №1.— С. 79-84.- 1998.
FIRE RESISTANCE OF 3D SYSTEM CEILING PANEL

R. Haddad and R. Alrousan

Dept. of Civil Engineering, P.O. Box 3030, Jordan University of Science and Technology, 22110 Irbid, Jordan

The endurance period for 3D wall and ceiling panel systems under a standard fire was experimentally determined. Experimental results were then validated using analytical modelling as well as nonlinear finite element analysis (NLFEA). The NLFEA model adopted was expanded to provide a parametric study of the 3D system wall and ceiling panels. Based on the experimental results, the wall and ceiling panel achieved a fire resistance rated at about 20 and 36 minutes, respectively, when tested as bearing assemblies with fire blaze applied against one surface using a mobile furnace, in accordance with ASTM Method E119-98. The theoretical analysis performed to predict the endurance time for the ceiling panel yielded very close results to those obtained experimentally: the theoretical temperature at failure that corresponded to 50% residual moment capacity was about 780°C, which is almost the same as that determined experimentally. The use of NLFEA allowed expanding the present results to include various configurations and dimensions for the 3D systems employed for future use in field.
INTERACTION BETWEEN CIRCULAR HOLES IN A PRESTRETCHED
ANISOTROPIC PLATE-STRIP UNDER PRESSURE

E. Hazar¹, M. Eröz¹, E. Nart², and I. Arda¹

¹Department of Mathematics, Faculty of Arts and Sciences, Sakarya University, 54187, Sakarya, Turkey
²Department of Mechatronics Engineering, Sakarya University, 54187, Sakarya, Turkey

In the present work, the investigations carried out in the paper [1, 2] is developed for certain different boundary conditions and obtained numerical results are compared with the situations in [1]. The following boundary value problem is considered:

\[
\frac{\partial}{\partial x_i} \left( \sigma_{ij}^{(k)} + \sigma_{mn}^{(0)} \frac{\partial u}{\partial x_n} \right) = 0, \quad \sigma_{11} = A_1 \varepsilon_{11} + A_{12} \varepsilon_{22}, \quad \sigma_{22} = A_{12} \varepsilon_{11} + A_{22} \varepsilon_{22},
\]

(1)

\[
\sigma_{12} = 2A_{16} \varepsilon_{12}, \quad \varepsilon_{xy} = \frac{1}{2} \left( \frac{\partial u}{\partial x_1} + \frac{\partial u}{\partial x_2} \right), \quad u_2 \mid_{x=0} = 0,
\]

(2)

\[
\left. \left( \sigma_{11} + \sigma_{1n}^{(0)} \frac{\partial u}{\partial x_n} \right) \right|_{x=0} = 0, \quad \sigma_{12} \mid_{x=H} = P \delta_i^2
\]

(3)

\[
\sigma_{12} \mid_{x=0} = 0, \quad \left( \sigma_{ji} + \sigma_{jn}^{(0)} \frac{\partial u}{\partial x_n} \right) n_j = 0,
\]

(4)

\[
\delta_i^2 = 0, \quad \delta_j^2 = 1, \quad i, j, n = 1, 2; k = 1, 2.
\]

The study is made within the scope of the piecewise-homogeneous body model with the use of the Three-Dimensional Linearized Theory of Elasticity.

The solution to the problem (1)–(4) is made by employing computer software ABAQUS. The numerical results illustrating the influence of the problem parameters on the stress distribution are presented.

REFERENCES

SMART COMPOSITE SANDWICH STRUCTURES BASED ON ELECTROACTIVE POLYMERS

M. Henke, J. Sorber, and G. Gerlach

Solid State Electronics Lab, Technische Universität Dresden, Germany
e-mail: Markus.Henke@TU-Dresden.de

The contribution describes a new kind of multi-layer flexure beam with a variable stiffness. These structures are supposed to be components of new smart, self-sensing and -controlling composite materials for lightweight constructions. To control the beams’ stiffness actuators based on Electroactive Polymer (EAP) foils from Danfoss PolyPower are used.

These beams are built up as multi-layer stacks of thin metal or polymethyl methacrylate (PMMA) plates. By influencing the connection between the single layers it is possible to strongly change the area moment of inertia. Thus the flexure beams can be in soft or stiff state (Fig.1a and b). This can be achieved by several ways, e.g. by controlling the sliding friction between the individual plates. Nevertheless, this effect is limited by the maximum shear stress that can be transferred by friction.

Fig. 1. Multi-layer beam: a) soft state, b) stiff state.

The novel solution proposed here provides a more efficient way to control the flexure stiffness. The internal structure of the multi-layer beam can be changed by EAP-driven actuators. These actuators consist of a supporting frame with a kind of interlocking structure and a multilayer stack of EAP foil. By moving the interlocking structure it is possible to block the sliding between the layers and stiffen the beam. Thus, it is possible to strongly change the stiffness of flexure beams. Thereby, the magnitude of varying the stiffness can be scaled by the number of layers as well as by the number and type of electroactive polymer-driven actuators used in the bending beam.

The contribution describes the detailed actuation mechanisms of actuators for controlling the moment of inertia. For interlocking the layers reliably it is necessary to generate a large actuation range. The supporting structure applies the necessary pre-straining force to the EAP foils. Usually, such structures have a constant spring stiffness which strongly limits the actuation range. The novel actuator (Fig. 2) shows highly nonlinear spring stiffness for pre-straining the foil. Therefore, the pre-straining force is nearly constant all over the actuation range. This leads to a doubling of the possible actuation range in comparison to that ones with constant spring stiffness.

Fig. 2. EAP actuator with non-linear force-deflection-behaviour.
ANALYSIS OF A CARBON-FIBER COMPOSITE WITH EMBEDDED ELECTRONICS

H. Herranen¹, J. S. Preden², J. Kers³, J. Majak¹, M. Pohlak¹, M. Eerme¹, A. Aruniit³, H. Lend¹, and G. Allikas³

¹Department of Machinery Tallinn University of Technology Ehitajate tee 5, 19086 Tallinn, Estonia
²Department of Computer Control Tallinn University of Technology Ehitajate tee 5, 19086 Tallinn, Estonia
³Department of Materials Engineering Tallinn University of Technology Ehitajate tee 5, 19086 Tallinn, Estonia

Embedding electronics in carbon fibre composites has value in future products where computing solutions are combined with mechanics. The created smart structure can be used in products where structural health monitoring is needed. When it becomes possible to embed computing devices in carbon fibre materials new types of smart objects can be created with very interesting properties from the product design perspective. However, little information is available on the properties of electronics-composite interaction in composite material. Closest embedded devices are embedded strain or acoustic wave sensing sensors. The influence of piezoelectric sensor on the structure has been estimated widely by many authors, e.g. Moita et al. [1]. Huang et al. [2] have simulated the influence of embedded micro-sensors on the unidirectional composite laminate.

The paper addresses the issue by embedding electronic components – an imitation for a complex electronic circuit – in the prepreg carbon fibre laminate during the lamination process. The change of the material mechanical strength due to presence of foreign objects in the laminate is assessed by experimental testing and finite element analysis. The design of the embedded electronic solution can be casing-free in order to use the extra support provided by the surrounding stiff composite structure. The strain interaction between electronics and carbon fiber laminate in thickness direction is measured with digital image correlation based deformation scanner GOM ARAMIS 2M. The results are analyzed and compared with finite element model simulation. Based on finite element modelling results the relationships between mechanical properties of the laminate and design parameters are modeled by use of the artificial neural networks (ANN). Based on experimental study, finite element modelling and the use of ANN a mathematical model for predicting mechanical properties of the carbon fiber laminates with embedded electronics has been developed.

REFERENCES

ASSESSMENT OF THE STABILITY OF A SURFACE CRACK IN LAMINATES

P. Hutař, M. Ševčík, L. Náhlík, and Z. Kněsl

Institute of Physics of Materials, Žižkova 22, 616 62 Brno, Czech Republic

Laminates are perspective type of composites due to theirs effective material properties. The lay-up of two or more homogenous layers finally leads to orthotropic structure with excellent mechanical properties, such as high impact resistance, low weight etc. The drawback of some laminates is low fracture toughness. Critical for laminate failure is the behaviour of surface cracks propagating through the first layer and their interaction with the corresponding interface. Once the crack propagates through the material interface from a compliant material to a stiff material a failure of a whole laminate can occur.

In the present paper, a numerical analysis of a crack arrested at the interface between two dissimilar homogenous materials is performed. The tension loading of the structure is assumed. The crack face is normal to the interface so that the only mode I of loading is assumed. The laminate lay-up structure is ABAB (Fig. 1). The crack front shape in material A is estimated under assumption of constant stress intensity factor along the crack front. The stress field at the material interface is described using generalized stress intensity factor. Utilizing of the concept of the strain energy density factor can assess whether the crack will propagate through the material interface or will growth only sideway. This methodology is here applied to the laminated composite. The main aim of this work is to study the influence of a thickness ratio \( t_A/t_B \) of the laminate on the crack behaviour at the material interface, see Fig. 1.

Fig.1. Geometrical configuration of the studied laminate containing surface crack arrested at the material interface.

Presented results can be helpful with design of new laminated composites by improving theirs fracture properties, namely enhances the effective fracture toughness.

Acknowledgement: This work was supported by grant P108/12/1560 of the Czech Science Foundation.

REFERENCES

EXPERIMENTAL AND THEORETICAL INVESTIGATION OF DEFORMATION AND FRACTURE OF HUMAN BODY FAT UNDER COMPRESSION

A. V. Ignatova and S. B. Sapozhnikov

Department of Physics, South Ural State University, 454080, Chelyabinsk, Russia

Under local impacts to the human chest (due to sporting fights, road accidents, impact of bullet through body armour, etc.) the first thing begins to deform the outer soft tissues: fat, muscles and skin. For example, fat is served as a damper under impact, reducing forces applied to the skeleton. Therefore, in present paper, fat is considered as a structural material, which is loaded by large displacement and can realize significant inelastic strains and fracture under uniform compression. In this work human fat was modeled by swine fat.

Compression experiments were performed on specimens dimensions 20×20×10 mm using the universal testing machine Instron 5882 with plate's rate 1…25 mm/min at room temperature. Range of experimental "force – strain" curves is shown on Fig.1 by grey zone. There are three parts on these curves: 1. 'non-linear elastic' at the strain less 45…50 %; 2. 'softening' at strain 50…70 %; and 3. 'hardening' at the strain more than 65…70%. Experimental data have significant dispersions by the nature of fat, which were minimized by choosing fat for experiments from one region of swine body.

![Fig. 1. Curves “compression force – strain” for swine fat.](image)

In the theoretical part of work, fat was modeled by parallel set of cells working independently up to failure. The cell is a closed thin-walled cylindrical shell with incompressible fluid inside. In this model, all cells have full geometrical identity (diameter and wall thickness are known from microscopy) but fracture strains of cell walls were described by two-parameter's Gaussian statistical distribution. Material of cell wall is hyperelastic (three parameters).

All cells were damaged at the strain more than 65 % and then empty broken cells work in compression only (hyperelastic model with two parameters).

So, only seven parameters are needed for identifying the mathematical model of fat compression (Fig.1, solid line). By the way, the tensile strength of fat cell walls is about 0.7…1.1 MPa. These data were used for numerical model of human torso under local hit, which corresponds to the impact through the bullet resistant vest.
STRUCTURE AND MECHANICAL PROPERTIES OF CELLULOSE NANOCRYSTALLITES

M. Ioelovich\textsuperscript{1} and O. Figovsky\textsuperscript{2}

\textsuperscript{1}Disinger Energy Ltd, 76100, Rehovot, Israel
\textsuperscript{2}Polymate INRC, 23100, Migdal HaEmek, Israel

As known, native cellulose is crystalline polymer that built of nanocrystallites 3-10 nm in width and 60-100 nm in length. Various cellulose specimens isolated from tunicin and different plants have the monoclinic C\textsuperscript{1}B\textsuperscript{2} crystalline structure with space group P2\textsubscript{1}. Detailed studies show that parameters of elementary unit cell of cellulosates of various origins are not constant but vary in the certain range due to distortion of the nanocrystallites caused by self deformation of nanocrystallites under the effect of the Laplace’s strain.

In this paper, the parameters of crystalline unit cell of various cellulose samples were determined by precise X-ray technique. As a result, a linear dependence of the parameter ($X$) on dispersity ($D$=1/L) of the nanocrystallites was observed: $X=f(D)$, where $L$ is lateral size of the nanocrystallites. Based on the micro-strain mechanisms, longitudinal (Young) modulus, transverse modulus, as well as modulus of volume deformation of cellulose nanocrystallites were calculated by the equation: $M=2\sigma X_o/k$, where $\sigma$ is surface energy of crystallites; $X_o$ is parameter of the unit cell for macrocrystal ($D = 0$); $k = \Delta X/\Delta D$ is coefficient experimentally determined from the dependence $X=f(D)$.

The determined Young’s modulus (YM) of cellulose crystallites was 150-155 GPa, transverse modulus (TM) 14-16 GPa, while volume modulus (VM) was about 3-4 GPa (Table 1).

<table>
<thead>
<tr>
<th>$X$</th>
<th>$X_o$</th>
<th>$k$</th>
<th>Modulus, GPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c$</td>
<td>1.0337 nm</td>
<td>0.0026–0.0028 nm$^2$</td>
<td>150–155 (YM)</td>
</tr>
<tr>
<td>$b$</td>
<td>0.815 nm</td>
<td>0.020–0.023 nm$^2$</td>
<td>14–16 (TM)</td>
</tr>
<tr>
<td>Volume</td>
<td>6.024×10$^3$, m$^3$/kg</td>
<td>6–8×10$^8$, m$^2$ nm/kg</td>
<td>3–4 (VM)</td>
</tr>
</tbody>
</table>

The determined moduli are in the range obtained by other researchers: YM=140–170 GPa and TM=11–18 GPa [1–3] that confirms the proposed micro-strain distortion mechanism causing variability of unit cell parameters of crystallites.

REFERENCES

DEFLECTION AND CRACKING ANALYSIS OF GFRP-REINFORCED BEAMS
BASED ON THE STRESS TRANSFER APPROACH

R. Jakubovskis¹, G. Kaklauskas¹, V. Gribniak¹,2, A. Weber³, and M. Juknys⁴

¹Department of Bridges and Special Structures, Vilnius Gediminas Technical University (VGTU), Vilnius 10223, Lithuania
²Department of Strength of Materials, VGTU, Lithuania
³Schöck Bauteile Ltd, Baden-Baden 76534, Germany
⁴Department of Structural Mechanics, VGTU, Lithuania

Glass fibre reinforced polymer (GFRP) is the most popular non-metallic reinforcement due to relatively low cost, high durability and strength. Although strength of GFRP bar is nominally greater than 1000 MPa, its deformation modulus reaches only 30–40% of steel. Therefore, deflection control of GFRP reinforced concrete beams becomes the governing design criteria.

As shown in figure 1, deformation and deflections of reinforced concrete members is highly related to cracking and tension-stiffening effects. The latter effect is referred to contribution of tensile concrete between cracks to the overall stiffness of a structure and should be the controlling factor for determining deflections, especially of lightly reinforced members [1]. Unlike steel, cracking is not dangerous for non-metallic bars due to high resistance for corrosion, but it is limited by aesthetic appearance of a structure. Moreover, crack pattern is indicator of bond behaviour, thereby tension-stiffening.

In this study, deformation, tension-stiffening and cracking behaviour of concrete beams reinforced by the Schöck ComBAR GFRP bars is analysed using stress transfer approach. This approach considers discrete cracking and uses the bond stress-slip model. Adequacy of the bond stress-slip models proposed in the literature is investigated comparing the predicted deflections of GFRP beams with the test results obtained by the authors.

Fig. 1. Deformational behaviour of a bending member.

REFERENCES

INVESTIGATION OF THE MECHANICAL PROPERTIES OF WELL-DISPERSED AL-CNT COMPOSITES PREPARED BY THE MODIFIED MECHANICAL ALLOYING METHOD

A. H. Javadi¹, Sh. Mirdamadi¹, M. A. Faghihisani¹, and S. Shakhesi²

¹Dept. of Materials Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
²Engineering Research Institute, Tehran, Iran

One of the major obstacles to the effective use of carbon nanotubes (CNTs) as reinforcements in metal matrix composites is their agglomeration and poor distribution/dispersion within the metallic matrix. In order to tap into the advantages of the properties of CNTs (or CNFs) in composites, the high dispersion of CNTs (or CNFs) and strong interfacial bonding are the key issues which are still challenging. Modified mechanical alloying (ball milling) techniques have emerged as promising routes for the fabrication of carbon nanotube reinforced metal matrix composites. In order to obtain a homogeneous product, good control of the milling process, in particular control of the ball movement, is essential. The control of the ball motion during the milling leads to a reduction in grinding energy and a more homogeneous product. Also, the critical inner diameter of the milling container at a particular rotational speed can be calculated.

In the present work, we use conventional and modified mechanical alloying to generate a homogenous distribution of 2 wt. % CNT within Al powders. 99% purity Aluminium powder (Acros, 200mesh) was used along with two different types of multiwall carbon nanotube (MWCNTs) having different aspect ratios to produce Al-CNT composites. The composite powders were processed into bulk material by compaction, and sintering using a cylindrical compaction and tube furnace. Field Emission Scanning electron microscopy (FESEM), X-Ray diffraction (XRD), Raman spectroscopy and Vickers macro hardness tester were used to evaluate CNT dispersion, powder morphology, CNT damage, phase analysis, mechanical properties and crystal size determination. Despite the success of ball milling in dispersing CNTs in Al powder, it is often accompanied with considerable strain hardening of the Al powder, which may have implications on the final properties of the composite. The results show that particle size and morphology vary with milling time. Also, by using the mixing process and sonication before mechanical alloying and modified ball mill, dispersion of the CNTs in Al matrix improves. It is thus concluded that modified ball milling is attractive manufacturing technique for the fabrication of CNT-reinforced aluminium with enhanced mechanical properties. However, careful selection of the type and amount of CNT, the milling conditions and the processing parameters should be exercised.

REFERENCES

MECHANICAL PROPERTIES OF A RAPIDLY PROTOTYPED COMPOSITE: NUMERICAL MODELING AND PARAMETRIC ANALYSIS

N. Jekabsons¹, U. Locans¹, and R. Joffe²

¹Ventspils University College, ITF faculty, Inženieru-101, LV-3605, Ventspils, Latvia
²Luleå University of Technology, Division of Materials Science, S-97187, Luleå, Sweden

Previous work by the authors [1-3] on rapid prototyping composite (gypsum/epoxy) was done with respect to the experimental characterization of mechanical properties and morphology study. This current paper deals with development of numerical homogenization models, capable to predict mechanical properties of gypsum composite as well as other similar materials with unconnected stiff inclusions (particles) and considerable amount of voids.

Large number of elements was needed to build up 3D representative unit cell (RUC) with realistic particle and void size and shape distributions. Due to numerical complexity, parallel calculations were carried out with the in-house developed FEM code. This code was verified by cross-comparison of some of results with commercial FEM package ANSYS.

The detailed digital model of gypsum/epoxy composite, containing accurate gypsum particle and void distribution was employed as RUC. The SEM micrograph of material along with example of 3D model used in calculations are shown in Fig. 1. The results of numerical modeling were compared with experimental results and predictions of simpler micromechanical models. Numerical modeling was also used to perform comprehensive parametric analysis with respect to mechanical properties of composite. Particle content, size and orientation of particles, and porosity (void content, distribution and geometry) were varied. The analysis of modeling results revealed an important role of void location and size distribution which may be related to percolation effects of inter-grain stress transfer.

Fig. 1. Micrograph (left) and example of model (right) of composite used in simulation.

REFERENCES

VIBRATION OF ANISOTROPIC STEPPED PLATES WITH CRACKS

E. Kägo and J. Lellep

Institute of Mathematics, University of Tartu, Estonia
e-mails: esta20@ut.ee, jaan.lellep@ut.ee

Vibration analysis of thin anisotropic rectangular plates is carried out using a classical theory and an approximate solution technique. The characteristic equation is obtained from the linear homogeneous algebraic system with vanishing determinant. The versatility of this approach is demonstrated by considering a rectangular plate with two opposite edges simply supported, and with classical boundary conditions (free, clamped, or simply supported) on the other two edges.

Our method handles the case where the plate has a part-through crack at the re-entrant corner of the step. This crack is modelled in the form of a continuous line spring parallel to one edge of the plate. We analyze the plate with different crack sizes.

Vibration frequencies are obtained for the plates with varying step thickness ratios. The influence of the step length, step thickness and crack depth ratios on the vibration behavior of rectangular anisotropic plates is examined.

Numerical results are presented here for the natural frequencies of the two-stepped anisotropic plates. The results of numerical computations are compared with results of theoretical and experimental data presented in the literature.

REFERENCES

Two main disadvantages of concrete as a structural material are its low tensile strength and brittleness. Adding steel fibres enhances post-cracking tensile residual strength, thus improving toughness and ductility. Therefore, in last decades fibre reinforcement is widely used as additive for concrete mixture. One of the most critical points in the theory of steel fibre reinforced concrete (SFRC) is quantifying the residual stresses in tension for a cracked section. In the present practice, the residual stresses are quantified by means of standard bending tests.

The paper presents a simple discrete crack model for analyzing the crack width and deformation of SFRC members subjected to tension. The model is based on a simplified non-iterative algorithm and uses a rigid-plastic bond-slip law and elastic properties of materials. Residual stresses were quantified by the three-point bending test of notched beam. SFRC members with different fibre contents were investigated. Comparative analysis of SFRC and plain reinforced concrete was performed, showing the effect of fibres. Specimens with steel fibres have shown to have smaller crack spacing, which contributed to a reduction in crack widths and deformation of the member (Fig.1). Deformations and crack widths predicted by the proposed technique were checked against the test results and reasonable agreement was achieved.

Fig. 1. Crack pattern and strain distribution: concrete member (a); SFRC member (b).
NUMERICAL ESTIMATION OF FIRE-RESISTANCE AND FLEXIBLE DESIGN OF FIRE PROTECTION FOR STRUCTURES OF REINFORCED MATERIALS

V. O. Kaledin, A. B. Mitkevich, and V. L. Strakhov

Central Research Institute for Special Machinery (TSNIISM) Zavodskaya St., Khotkovo, Moscow Reg., 141371, Russia

The basic provisions of the progressive methodology for calculation of fire resistance and required thicknesses of fire protection of reinforced building structures for application in high-rise, multi-functional and unique construction facilities are presented. The methodology is universal in respect of materials, types of building structures with fire protection and different power and heat loads acting on theirs under conditions of fire. It permits to take into account all the main particularities of thermomechanical behavior of structures in case of joint effect of fire and power load.

The solution procedure is based on using the high-level mathematical models and the universal means of the numerical analysis, i.e. Finite Element Method (FEM) and Finite Difference Method (FDM).

To simplify and reduce the labour intensity of computational algorithms, a mathematical model of special beam finite element has been developed that in the natural way takes into account intricate structure of building constructions, spatial nonuniformity of temperature field and non-linear behaviour of the materials. This procedure allowed us to determine the boundaries of applicability of the known approximate approach, based on the use of such concept as “critical temperature”, to the fire resistance estimation and design of the fire protection of concrete structures. The procedure has been used in designing a number of unique structures built in Moscow.
COMPRESSIVE STRENGTH OF CONCRETE WITH A GROUND GRANULATED BLAST FURNACE SLAG

P. Kara, A. Korjakins, and R. Gulbis

Riga Technical University, Institute of Materials and Structures, Professor Group of Building Materials and Products 1 Kalku str., Riga, LV-1658, Latvia

Ground Granulated Blast Furnace Slag (GGBS) is a by-product of the manufacturing of iron in a blast furnace where iron ore, limestone and coke are heated up to 1500°C.

Waste and supplementary cementing materials such as blast furnace slag, fly ash, and waste glass can be used as partial replacements for Portland cement. Partial cement replacement by these materials can improve concrete mechanical properties; reduce energy and CO₂ emissions in comparison with cement 100% usage. In present study twelve concrete mixes with various water/binder ratios and achieved compressive strength at the age of 28 days were considered. Standard testing sample 100×100×100 mm cubes for 13 concrete mixes were produced. Two days later the samples were dismantled. Standard curing conditions (temperature 20±2°C, RH > 95±5%) were provided during the process of concrete hardening. Compressive strength of hardened concrete samples was determined at the age of 7, 28 and 56 days. Compression testing machine with the accuracy of ±1% was used, the rate of loading was 0.7 MPa/s (according to LVS EN 12390-3:2009 standard).

The produced concrete mixes composition and achieved compressive strength are following: (1) control mix (w/b =0.45, 63 MPa), (2) 70% replacement of cement with blast furnace slag grinded by 30 min (w/b =0.45, 11.1 MPa), (3) 50% replacement of cement with blast furnace slag (w/b =0.45, 25 MPa), (4) 50% replacement of cement with blast furnace slag (w/b =0.35, 48 MPa), (5) 25% replacement of cement with blast furnace slag and fly ash grinded by 30 min (w/b =0.57, 30 MPa), (6) 25% replacement of cement with blast furnace slag grinded by 30 min and waste glass (w/b =0.57, 26 MPa), (7) 25% replacement of cement with blast furnace slag and wood ash grinded by 30 min (w/b =0.57, 28 MPa), (8) 25% replacement of cement with blast furnace slag grinded by 30 min and waste glass (w/b =0.44, 45 MPa), (9) 25% replacement of cement with blast furnace slag grinded by 30 min and waste glass (w/b =0.5, 39 MPa), (10) 20% replacement of cement with blast furnace slag grinded by 30 min and superplasticizer (w/b =0.36, 69MPa), (11) 20% replacement of cement with blast furnace slag by 30 min (w/b =0.49, 48 MPa), (12) 20% replacement of cement with blast furnace slag grinded by 30 min and superplasticizer (w/b =0.49, 41MPa). The best result for compressive strength was achieved by minimizing w/b ratio and addition of superplasticizer into the mix (10).

REFERENCES

THE USAGE OF A WASTE GLASS POWDER AS A MICROFILLER IN UHPC

P. Kara, A. Korjakins, and K. Kovalenko

Riga Technical University, Institute of Materials and Structures, Professor Group of Building Materials and Products, 1 Kalku str., Riga, LV-1658, Latvia

United Nations estimates the volume of yearly disposed solid waste to be 200 million tons, 7% of which is made up of glass the world over (Topcu and Canbaz, 2004). Non-recycled waste glasses are generally dumped into landfill sites but with the shortage of landfill sites, land filling is becoming more and more difficult. Since the glass is not biodegradable, landfills do not provide an environment-friendly solution. Therefore, there is strong need to utilize waste glasses.

In present study was investigated: the possibility to raise the activity of waste glass powder as micro filler by its additional grinding for 30 min and usage of superplasticizer in order to raise compressive strength of concrete.

Standard testing sample 100×100×100 mm cubes for 13 concrete mixes were produced. Two days later the samples were dismantled. Standard curing conditions (temperature 20±2°C, RH > 95±5%) were provided during the process of concrete hardening. Compressive strength of hardened concrete samples was determined at the age of 7, 28 and 56 days. Compression testing machine with the accuracy of ±1% was used, the rate of loading was 0.7 MPa/s (according to LVS EN 12390-3:2009 standard).

Control mix with cement 410 kg/m³ amount achieved compressive strength of 46, 57, 66 MPa at the age of 7, 28, 56 days accordingly. The compressive strength of concrete made with varying percentages (20, 30, and 40 by weight of cement) of waste glass powder and additionally ground for 30 min waste glass powder were determined. The mix with the additionally ground waste glass powder and superplasticizer showed the increase of compressive strength for 30%. The best compressive strength results were achieved for mixes with 20% waste glass powder replacement of 67, 94, 101 MPa (7, 28, 56 days). The results of compressive strength for mixes with 30% waste glass powder replacement showed higher values than control concrete mix but lower for mixes with 40% waste glass powder replacement.

Acknowledgement. Financial support of the ERAF project Nr. 2010/0286/2DP/2.1.1.1.0/10/APIA/VIAA/033 „High efficiency nanoconcretes” is acknowledged.

REFERENCES

MECHANICAL PROPERTIES OF HEMP-FIBRE-CONCRETE STRUCTURAL ELEMENTS

P. Kara, A. Kojakins, and K. Kuznecovs

Riga Technical University, Institute of Materials and Structures,
Professor Group of Building Materials and Products, 1 Kalku str., Riga, LV-1658, Latvia

Natural hemp fibers increase scientific interest in applications of construction elements what can be described by the good mechanical properties exhibited by these natural fibers. It can be observed that the tensile strength can reach more than 1000 MPa, in case of flax fiber and vary from about 400 MPa to 800 MPa in case of jute fiber, whereas hemp fiber exhibits a tensile strength of 690 MPa. Furthermore, the ultimate tensile strain varies from 1.5% for the jute fiber to 3.2% for the flax fiber, whereas hemp fiber presents an ultimate tensile strain of 1.6%. Young’s modulus is equal to 26.5 GPa and 27.6 GPa for jute and flax fiber, respectively, whereas, according to Dhakal et al. Young’s modulus for hemp fiber varies from 30 GPa to 60 GPa. Therefore, natural fibers can be feasibly used as a component of composite construction materials. Hemp fibre concrete construction elements were produced. The mechanical behavior of hemp fibre concrete construction elements was studied through a three-point bending test.

REFERENCES

HIGH-EFFICIENCY NANOCONCRETE CONTAINING LOCAL INDUSTRIAL BY-PRODUCTS AND WASTES

P. Kara, A. Korjakins, and G. Shakhmenko
Riga Technical University, Institute of Materials and Structures, Professor Group of Building Materials and Products, 1 Kalku str., Riga, LV-1658, Latvia

The accumulation of local industrial by-products and wastes in the plants without being used represents two major problems: a solid waste disposal and a negative impact to the environment.

The environmental - energy and CO$_2$ - impact of concrete could be reduced by the usage of local industrial by-products and wastes (waste glass, coal ash) as passive micro-filler and recycled concrete as aggregate. In present paper the activation of passive micro-filler is suggested by calcinations, by additional grinding in laboratory planetary ball mill in water environment with and without superplasticizer and by cavitation treatment. The cavitation treatment is realized by patented apparatus [1] which creates turbulent flow and employs hydrodynamic cavitation process to achieve micro and nano particle disaggregation and surface activation. The particle grading was determined by Laser diffraction method. The influence on concrete compressive strength and particle packing is investigated. The concrete mixes with additionally ground borosilicate(DRL)/leaden(LB) waste glass suspension, activated coal ash as micro-filler by partial replacement of cement and crashed recycled concrete as aggregate were prepared. The concrete specimens were tested at the age of 7, 14 and 28 days (according to LVS EN 12390-3:2009 standard).

Acknowledgement. Financial support of the ERAF project Nr. 2010/0286/2DP/2.1.1.1.0/10/APIA/VIAA/033 „High efficiency nanoconcretes” is acknowledged.

REFERENCES
THE EFFECT OF MINERAL ADMIXTURES SUCH AS COAL AND WOOD ASHES ON THE COMpressive STRENGTH OF CONCRETE

P. Kara, A. Korjakins, and V. Stokmanis-Blaus

Riga Technical University, Institute of Materials and Structures, Professor Group of Building Materials and Products 1 Kalku str., Riga, LV-1658, Latvia

Landfilling is becoming very restrictive due to shrinking landfill space and strict environmental regulations, CO₂ emissions from cement industry must be reduced, thus substituting part of the cement clinker with by-products or waste materials such as coal/wood ashes is one of the solutions for these problems. Coal ash (CA) and wood ash (WA) are the residues generated due to combustion of coal/wood and coal/wood products. In present study coal/wood ashes and additionally ground fly coal /wood ashes for 30 min in laboratory planetary ball mill were used as partial substitution of cement at 3 levels 20, 30, and 40% in concrete mixes.

Standard testing sample 100×100×100mm cubes were produced. Two days later the samples were dismantled. Standard curing conditions (temperature 20±2°C, RH > 95±5%) were provided during the process of concrete hardening. Compressive strength of hardened concrete samples was determined at the age of 7, 28 and 56 days. Compression testing machine with the accuracy of ±1% was used, the rate of loading was 0.7 MPa/s (according to LVS EN 12390-3:2009 standard).

Control mix with 410kg/m³ cement amount achieved compressive strength of 46, 57, 66 MPa at the age of 7, 28, 56 days accordingly. The compressive strength of mix with 20% of additionally ground fly coal ash achieved almost the same value of compressive strength of control mix of 68 MPa at age of 56 days. The results for 30% replacement by fly coal ash with additional grind by 30 min at the age of 7, 28, 56 days showed compressive strength of 34, 47, 58 MPa. The results for 40% cement replacement by coal ash at the age of 7, 28, 56 days showed compressive strength of 28, 38, 51 MPa.

The compressive strength of concrete made with varying percentages (20, 30, and 40 by weight of cement) of wood ash generally increased with age (7, 28, 56 days) but decreased with the increase in the WA content (35, 44, 51 MPa for 20% of WA, 31, 41, 52 MPa 30% of WA, 25, 39, 42 MPa 40% of WA). Comparisons of the compressive strength of WA concrete with those of the control concrete mix of corresponding ages showed that the compressive strength of WA concrete was less than that of the control concrete mix and coal ash concrete mix.

Acknowledgement. Financial support of the ERAF project Nr. 2010/0286/2DP/2.1.1.1.0/10/APIA/VIAA/033 „High efficiency nanoconcretes” is acknowledged.

REFERENCES

INFLUENCE OF CRACKS AND MATERIAL MICROSTRUCTURE ON AN INTERFACE CRACK IN FUNCTIONALLY GRADED/HOMOGENEOUS COMPOSITE BIMATERIALS SUBJECTED TO ANTIPLANE LOADING

N. Karaulova and V. Petrova

Faculty of Mathematics, Voronezh State University, 394006 Voronezh, Russia

The work is devoted to modeling of the fracture processes in the vicinity of an interface in a bimaterial compound which consists of a functionally graded material (FGM) and a homogeneous material. The bimaterial contains an interface crack and arbitrary located internal cracks in the FGM and is subjected to antiplane shear loading. It is assumed that shear modulus of the FGM possess an exponential form. A theoretical analysis of the problem is performed by means of singular integral equations. These integral equations are solved numerically by method based on the Chebyshev polynomials. The stress intensity factors (SIFs) for the interface crack is derived and compared with the approximate analytical solution obtained previously by method of small parameter for a case where the interface crack length is larger than nearby internal cracks in the FGM (the small parameter is equal to the ratio of the size of small internal cracks to the interface crack size). The advantage and disadvantage of these two methods are discussed.

The SIFs at the interface crack tips can be amplified or shielded by the system of cracks. These regions are obtained for different geometrical and material parameters. The applicability of these results for actual material combinations of FGMs such as: ceramic/ceramic, e.g., TiC/SiC, MoSi2/Al2O3 and MoSi2/SiC, and also ceramic/metal FGMs, e.g., zirconia/nickel and zirconia/steel, are discussed and demonstrated. In each case of actual FGM, the values of their inhomogeneity parameters are estimated. The study can be used for analytical modeling the residual stress-strain distribution near interfaces in FGM/homogeneous bimaterials under antiplane loading, for the purpose of optimizing the architecture of the interface to resist failure.
NUMERICAL MODELING OF SINGLE STEEL FIBER PULL OUT OF CONCRETE

O. Kononova, A. Krasnikovs, A. Galushchak, V. Zaharevsky, and E. Machanovsky

Institute of Mechanics, Riga Technical University, LV-1658, Riga, Latvia

It is well known that the main disadvantage of concrete is its low tensile strength. Due to this fact, concrete tends to crack even under relatively low level of applied acting forces and for this reason it is used mainly in the form of reinforced concrete. It has been proved by many researchers that the overall behavior of concrete can be improved by the addition of fibers. A wide range of fibers is used for the production of fiber reinforced concrete (steel, plastic, glass, etc.). The positive effect of the fibers is not obvious until the first crack occurs in the concrete. Increasing the applied loads the matrix fracture process is initializing: micro-cracks start to open to grow and to coalesce finally forming one or few macro-cracks. The fibers are bridging the crack. Each fiber pull-out process is starting with debonding between fiber and concrete matrix [1, 2] and is resulting to fiber sliding with friction out of concrete matrix.

The present study is limited to the use of steel fibers. Attention is restricted to the systems with residual compressive stress acting across the fiber/matrix interface. Single fiber pull-out law was determined experimentally for fibers embedded into concrete at different depth and under different angle [2]. The configuration of the moulded specimen and its dimensions are given in Fig.1. In Fig.1 \( l_f \) shows the embedded length of the fiber (that will be subjected to pull-out) and \( \alpha \) is the inclination angle of the fiber with respect to the applied pull-out load direction. The same pull-out curves were obtained numerically using FEM simulations. Fiber is sliding with friction and is deforming (bending) elasto-plastically when is pulling out of the curved channel in concrete matrix. The results of the numerical model are compared with experimental data and were discussed.

![Fig. 1. Configuration of a pull-out test specimen.](image)

REFERENCES

CARBON NANOTUBES AS MODIFIERS OF EPOXY-POLYSULFONE MATRICES FOR UNIDIRECTIONAL ORGANIC-FIBER-REINFORCED PLASTICS

R. A. Korokhin, V. I. Solodilov, Yu. A. Gorbatkina, and A. M. Kuperman
Semenov Institute of Chemical Physics of Russian academy of Sciences, Kosygin Str. 4, Moscow, Russia

Carbon nanotubes (CNTs) have unique properties and may be used as modifiers in order to improve physical-mechanical properties of polymer composite materials. Recently epoxy matrices modified with thermoplastic polymers have been applied for increasing fracture toughness of composites. The present paper deals with the study of the effect of CNT on mechanical properties of organic fiber reinforced plastics (OFRP) based on epoxy-polysulfone matrices.

Matrix components were as follows: the ED-20 epoxy oligomer, the PSK-1 polysulfone and multiwall CNTs ($l = 5 – 15 \mu m$, $d = 40 – 60 \text{ nm}$). Unidirectional composites were fabricated by “wet” winding with the Rusar aramide fiber. Concentration of CNT within the epoxy-polysulfone matrix varied from 0.3 to 1% of the ED-20 wt.

It is shown that the introduction of polysulfone into the epoxy matrix two times increases the crack resistance of OFRP. The introduction of 0.3% of CNTs practically does not change the specific fracture toughness. Further increasing of nanotubes content decreases the fracture toughness (Fig. 1)

Introduction of CNT into the polymer matrix does not affect the shear strength of OFRP under quasi-static loading rate (11 and 80 mm/min). However such modification can be very effective under low rate impact (4.0 and 5.4 m/s). For example, the shear strength increases by 10-15% for OFRP based on the ED-20 + PSK-1 (20%) + CNT (0.3%) matrix as compared to the shear strength of composites with matrix includes only PSK-1. The total increase of the shear strength is 40% (with respect to initial plastic based on non-modified epoxy resin).

Thus, the modification of epoxy-polysulfone matrices with minor CNT additives enables one to increase the shear strength of OFRP without any reduction of their fracture toughness.
ANALYSIS OF THE SHEAR STRENGTHENED OF A RC FRAME WITH NEAR-SURFACE MOUNTED FRP BARS

A. Kosarian¹ and M.-K. Sharbatdar²

¹M.S Student, Faculty of Civil Eng., Semnan University, Semnan, Iran
²Assistant Professor, Faculty of Civil Eng., Semnan University, Semnan, Iran

A near surface mounted (NSM) strengthening technique was developed to increase the shear resistance of concrete beams. The NSM technique is based on fixing with epoxy adhesive Carbon Fiber Reinforced Polymer (CFRP) laminates into pre-cut slits opened in the concrete cover of lateral surface of beams. Verification was based on simulating in ABAQUS three shear strengthened beams tested in experimental program by J. A. O. Barros et al: without any shear reinforcement; and a beam strengthened with NSM procured laminates of CFRP that positioned at 90° in relation to the beam axis. To assess the efficacy of this technique, an analytical modeling program of four frames was carried out with reinforced concrete frames failing in shear in ABAQUS. One of them had without rehabilitation, the second frame strengthened with NSM CFRP rods positioned at 90°, the third frame strengthened with NSM CFRP rods positioned 45° asymmetry inclined and the fourth ones strengthened with NSM CFRP rods positioned 45° symmetry V shape. Amongst the CFRP strengthened technique, the NSM with CFRP rods at 45° symmetry V shape was the most effective, not only in terms of increasing beam shear resistance in frame but also in assuring larger deformation capacity at beam failure.

Fig. 1. Sample of modelling RC frames in ABAQUS.

REFERENCES

THE INFLUENCE OF INTERACTION BETWEEN PERIODICALLY LOCATED ROWS OF FIBERS IN A COMPOSITE MATERIALS ON THE DISTRIBUTION OF STRESSES

R. Kosker¹, S. D. Akbarov²,³, and Y. Ucan¹

¹Yildiz Technical University, Faculty of Chemical and Metallurgical Engineering, Dep. of Mathematical Engineering, Davutpasa Campus, 34210 İstanbul, Turkey
²Yildiz Technical University, Faculty of Mechanical Engineering, Department of Mechanical Engineering, Yildiz Campus, 34349, Beşiktas, Istanbul-Turkey

Curvature of fibers in structure of composite materials may occur as a result of design, or as a consequence of some technological process, as mentioned in [1]. It is known that these curvature causes to arise self-balanced stresses and the values of these stresses can pass over adhesion resistance values. According to these and various other reasons, it is needed mechanics of composite material with curved structure. The widely explanation and interpretation of investigations carried out on these subjects are given in [1]. However in [1], the concrete numerical investigations of stress for unidirectional composites with curved fiber are done for only insignificant concentration of fibers and in this case, composite material is modelled as an infinite elastic body containing a single periodical curved fiber. For investigation such a problem a method is developed in [2] and numerical results are obtained. Therefore, in [3] the foregoing approach was developed for a periodically located row of fibers in an infinite matrix and corresponding numerical results were presented. In this paper it was assumed that the curving of the fibers relative to each other is sinphase one and the investigations were made within the framework of the linear theory of elasticity. In [4], the previous investigation is developed for the antiphase curved row fibers in an infinite matrix. In [5], numerical results on the effect of the geometrical non-linearity to the values of the self-balanced shear and normal stresses are studied for the cases where the location of the fibers according to each other the sinphase and antiphase curving cases.

In this study, with respect to the location of the fibers according to each other the co-phase curving out of plane are considered. It is assumed that the middle lines of the fibers are located on the different and parallel planes and the curving of these lines are periodic and co-phase. The stress distribution is studied when the body is loaded at infinity by uniformly distributed normal forces with intensity p acting in the fibers direction.

The investigation is carried out in the framework of the piecewise-homogeneous body model with the use of the three-dimensional geometrical non-linear exact equations of the elasticity theory. Consequently, in present investigation the effect of the geometrical non-linearity to the considered stress distribution is also studied. The numerical results illustrated the influence of the distance between the fibers to the self-equilibrium stress distributions are given.

REFERENCES

NANOTRIBOLOGY AND MICROMECHANICS OF POLYSTYRENE-NANOCLAY COMPOSITES

S. V. Kotomin¹, I-Ta Chang², E. Sancaktar², and D. Iarikov³

¹Polymer Rheology Lab, Institute of Petrochemical Synthesis, Moscow, Russia
²Polymer Engineering, University of Akron, Akron, OH, USA
³Chemical Engineering, Virginia Tech, Blacksburg, VA, USA

Atomic Force Microscopy is a powerful method to study surface properties of nanocomposites. Lateral Force Mode is a new AFM application to study nanotribological characteristics of composite samples. The objective of this study was to explore some surface properties of polymer nanocomposites with polystyrene matrix and nanosilicate filler - montmorillonite Cloisite 20A. Samples were prepared by injection molding of thermoplastic composite pellets after melt blending the dry-mixed PS/clay mixtures in a twin-screw co-rotation compounder. Micromechanical properties were studied on a HYSITRON nanoindenter, and lateral force microscopy was carried out on an AFM Asylum MPF 3D with Brucker silicon nitride cantilever. Micromechanical properties obtained on nanoindenter correlate well with macromechanical data, indicating some decrease in modulus, strength and microhardness after introduction of the filler up to 10 wt %, with minima occurring at 1–3 wt. % (Fig. 1) Nanofriction study in lateral force microscopy demonstrated noticeable increase in friction coefficient at 1 wt. % clay content, which correlates with decrease of modulus and strength for these composites (Fig. 2).

Rather smooth picture of lateral force change while moving cantilever along surface of homogeneous polymer changed drastically after introduction of the clay, resulting in saw-like profile of the curve which indicates stick-slip character of friction on the composite surface. Frequency of cantilever tip oscillations rises with content of the filler.

Fig. 1. Micromechanics of PS nanocomposites.
Fig. 2. Friction coefficient vs clay content.

Observed phenomena can be explained from the position of intermediate layer formation between the composite surface and the cantilever tip. Low strength and modulus of surface, at certain content of the filler, promote easy formation of intermediate polymer layer in friction area, adhesive interaction with the cantilever tip, and thus, an increase in friction. It is important to note that friction is rather sensitive to direction of flow during processing, thus providing the potential for evaluation of nanofiller orientation during flow.
The carbon fibre reinforced plastics (CFRP) are superior to metals in their specific strength and stiffness. CFRP have also higher damping ratios than metals [1, 2]. In cases where high value of the damping ratio is important, the damping ratio can be increased using a hybrid laminate consisting of the CFRP layers and rubber-cork layers. However, it can result in lower strength and stiffness. Therefore, analysis of optimal laminate layup is required.

This work deals with experimental and finite element analyses of hybrid square tube consisting of layers with high modulus fibres and ACM87 rubber-cork layers. Pareto optimization was performed using the three-dimensional numerical simulation with the aim to maximize the fundamental natural frequency, the static bending stiffness and the damping ratio. The Rayleigh damping with constant damping ratio of CFRP and rubber-cork layers was assumed in the numerical simulation [3]. In case of experiments, dynamic characteristics were investigated using the optoNCDT laser measurement device and Brüel&Kjaer 4507 accelerometer and compared with the numerical simulation. The filament winding technology was used for producing of the CFRP layers of the experimental samples.

Fig. 1. Hybrid square tube.

This work was supported by the European Regional Development Fund, project “NTIS – New Technologies for Information Society”, European Centre of Excellence, CZ.1.05/1.1.00/02.0090 and by the research project of the Ministry of Education of Czech Republic no. SGS-2010-046.

REFERENCES
OPTIMAL DESIGN AND EXPERIMENTAL VERIFICATION OF A FULL-SCALE COMPOSITE ROTOR BLADE WITH MACROFIBER COMPOSITE ACTUATORS

A. Kovalovs, E. Barkanov, and S. Gluhihs

Institute of Materials and Structures, Riga Technical University Kalku St. 1, LV-1658, Riga, Latvia

The aim of the present work is development of an active twist actuation concept for a reduction of vibration and blade-vortex interaction (BVI) noise of helicopters to improve their overall performance. Traditional vibration control methods for helicopters are based on the application of Higher Harmonic Control (HHC) and Individual Blade Control (IBC) methodologies. Due to the recent development of smart materials, new active control technique is implemented now for the control of rotor blades, reduction of their vibration and noise, as well as for an enhanced performance. This approach uses smart material actuation to achieve individual blade control without the need for complex mechanisms in the rotating frame. An application of such materials for the control is resulted in the production of innovative design - the active twist rotor. Active twist control of the rotor blades may be used to refuse the aerodynamic disturbances affecting the blades and in the real time enables an implementation of the active vibration control strategies.

The twist deformation of blade is obtained using Macro Fiber Composite (MFC) actuators embedded in the composite blade construction. Two active plies of MFC actuators is located at the top and bottom of the helicopter rotor blade and oriented at ±45° to the spanwise axis. An electric field activates the piezoelectric effect in the piezoceramic fibres of MFC actuators which elongate along the length of fibres and thus distribute a twisting movement along the blade.

The methodology based on the planning of experiments and response surface technique was developed for various geometric parameters of the blade and optimum placements of MFC actuators to achieve the maximal angle of twist. The optimisation problem was formulated on the results of parametric study and taking into account the producers requirements.

The finite element model of rotor blade was built using ANSYS finite element program. It was comprised of two different types of elements: linear layered structural shell elements SHELL 99 and structural solid elements SOLID 186 which were used to model different components of the blade. The design of this finite element model is based on the dimensions of full-scale BO-105 helicopter rotor blade. An investigated helicopter rotor blade is equipped with NACA23012 airfoil. The helicopter rotor blade consists of C-spar made of unidirectional glass-fibre reinforced plastic (UD GFRP), skin made of ±45° GFRP, foam core, balance weight and MFC actuators. In the static analysis the thermal strain analogy between piezoelectric and thermal strains is used to model piezoelectric effects when the piezoelectric coefficients characterising an actuator are introduced as the thermal expansion coefficients.

Verification of the finite element model of full-scale helicopter rotor blade with MFC actuators was made according to the static-twist experiments of the model-scale rotor blades in the German Aerospace Centre (DLR).
EFFECT OF MOISTURE ON THE MATERIAL PROPERTIES OF A COMPOSITE MATERIAL

A. Kovalovs\textsuperscript{1}, P. Serebrjakovs\textsuperscript{2}, and A. Sorokins\textsuperscript{3}

\textsuperscript{1}Institute of Materials and Structures, Riga Technical University, Riga, Latvia
\textsuperscript{2}Centre Composite, Joint venture of LNK group and Progresstech, Riga, Latvia
\textsuperscript{3}AVIATEST, LNK Group, Riga, Latvia

Nowadays, composite materials are widely used in the aeronautical industry to manufacture many different components. Development of composite materials has a very positive influence on the performance, reliability, weight and cost of modern aircrafts. But composite material in practical use can be subjected to a wide variety of different loading conditions: mechanical stresses and environmental influence. In this case very important to know the mechanical properties of composite materials after effect of environment such as water.

Water absorption and his effects on the mechanical properties of fiber composites is an important subject, because water absorption leads to change dimensions and reduce of mechanical properties.

The objective of this work is estimation of the influence of water absorption on mechanical properties of composite specimens. The material used in this study was manufactured in JSC “Voronezh Aircraft Manufacturing Company.” Test specimens were prepared according to procedure of GOST standard. Longitudinal tensile, transverse tensile and in-plane shear properties were studied.
1. Composite pipes are most important tendency in civil engineering.

2. Crosslink polyethylene pipes reinforced by high modulus fibers are widely applicable in Russia for district heating system with working temperature 95 and 115 degrees.

3. Flexible preisolated metal and polymer pipes are used in Russia for district heating system with working temperature 95 and 115 degrees.

4. Polymer composite pipes with the layer with special abrasive resistance and barrier properties are now applied in pipes for conveyance gas and water for human consumption.

5. Big diameter polymer composite pipes, which produce by winding technology with application glass- and metal reinforce liners, was applied in plastic piping systems for water supply and sewerage.

6. New methods for tear resistance of polymer matrix, which was cutting by reinforcing elements, was developed. Tear resistance was determined in widely temperature interval.
THERMAL STUDY OF A MODIFIED POLYURETHANE DISPERSION FOR LEATHER SURFACE DYEING

O. Kovtunenko\textsuperscript{1}, T. Travinskaya\textsuperscript{2}, and V. Plavan\textsuperscript{1}

\textsuperscript{1}National University of Design & Technology, Kiev, Ukraine
\textsuperscript{2}Institute of Macromolecular Chemistry NAS of Ukraine, Kiev, Ukraine

During the animal skin treatment the dynamic destruction of different bonds between albumen fibrous elements is occurred along with the new bonds formation as the result of interaction with used reagents. There are both synthetic and natural finishing materials among such reagents. Due to the environmental impact, economic and safety concerns the water based synthetic polymers are widely used in leather working. That is why the development of new film-forming materials for surface dyeing of leather by modification of environmentally-friendly polyurethane ionic dispersions (PUI) with collagen product (CP) and modified polyphosphate montmorillonite (MMT) is the crucial task of tanning industry. In this work the results of thermal destruction of the new modified PUI based coatings are presented (Table 1).

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|c|}
\hline
No. & modifier & \textit{T}_{\text{start}} & \textit{T}_{\text{end}} & \textit{T} & Weight & Stage & Coke \\
& & destruction & proc. & rate of & loss, \% at & of process, \textdegree C & residue, \\
& & \textdegree C & \textdegree C & decompos. & \textit{T}_{\text{max}} & & \% \\
& & & & \textdegree C & \textdegree C & & \\
\hline
1 & CP & 264 & 697 & 349 & 25.2 & II & 0.48 \\
2 & CP +Na\textsuperscript{+}: MMT & 308 & 622 & 408 & 18.2 & II & 9.95 \\
3 & CP + Chromic gelatin & 294 & 568 & 497 & 16.9 & II & 4.38 \\
4 & Chromic gelatin & 264 & 794 & 317 & 20.1 & II & 12.08 \\
\hline
\end{tabular}
\caption{Data of thermal oxidation destruction of modified PUI}
\end{table}

Notes: \textsuperscript{*}film of pure chromic gelatin.

The weight loss of all samples pass through the several stages with different intensities reflected the chemical and physical transformations during the heating. The number of decomposition stages, ratio of their intensities and temperature intervals are depended on modifier (Tabl. 1). The DTG curves are similar for all films, except the “chromic gelatin” (CG-imitate the tanned leather). Prolonged thero(destruction of CG (up to 794\textdegree C) includes multi-stages transformations: at the beginning – of chrome collagen, after 400\textdegree C- of chrome complex with final oxidation of intermediate products to chrome oxide. The coke residue of the sample amounts to 12 \%. Interval 264–355\textdegree C characterizes the thermo-oxidative destruction of urethane and urea groups. Since the urethane bond is the most weak in PUI, the thermal destruction is started from C-N bond degradation in -NH-CO-O- group with CO2 release (sample 1, stage II). Thermostability of samples (sample 3, stage II, III) is increased due to the presence of both polyurea and the product of organic and inorganic constituents’ interaction with obtaining of urethane-like structures: Si-O...H-C, Si-O-C, R-COO-Na-Si (sample 2, stage II, III). Thus, the introducing of inorganic fragments into the PUI structure changes the character and the rate of thermo-decomposition due to the change of dissociation energy of bonds as the result of additional interactions (Van-der-Waals, hydrogen etc.) with thermodestructive products. Modification of PUI with natural materials increases the thermostability of based skin film-making materials owing to chemical reactions between organic and inorganic parts of the system with the new structure formation.
COMPOSITE MATERIAL REINFORCED BY A KNITTED FABRIC. PREDICTION OF ITS STRENGTH AND ELASTIC PROPERTIES AND EXPERIMENTAL VALIDATION

A. Krasnikovs¹, O. Kononova¹, G. Harjkova¹, V. Zaharevsky¹, E. Machanovsky¹, S. Ruchevskis², and P. Akishins²

¹Institute of Mechanics, Riga Technical University, LV-1658, Riga, Latvia
²Institute of Materials and Structures, Riga Technical University, LV-1658, Riga, Latvia

Polymer composites reinforced by knitted fabric (see fig.1) are materials with high potential [1, 2]. In the same time such materials are mechanically non-linear with a high dynamic energy absorption possibility. Two different approaches were executed - numerical (FEM) structural modeling based on reinforcement and matrix mechanical and geometrical properties (were measured experimentally) and inverse method approach for mechanical properties appreciation, based on vibrations modal analysis; with the goal to obtain and predict well knitted fabric reinforced multilayered composite plate mechanical behavior.

Fig. 1. Layered Glass fiber/ Epoxy matrix [0]₄ composite laminate (geometrical simulation).

The modal vibration tests in combination with the mathematical optimization procedure are the method which was used for layered material elastic properties evaluation. Is worth to mention, that such approach application for materials with a high damping ability (laminated composites, reinforced by knitted fabric can be positioned as such materials) is still investigated poorly. The inverse technique version was exploited in the work is based on the direct orthotropic plate free vibration measurements and afterward mathematical optimization procedure (the planning of experiments or response surface technique) which is minimizing the error functional. Finally, the elastic constants were obtained by inverse technique were compared with the obtained by direct experimental measurements and FEM modeling data. Structural probabilistic CM fracture model was developed and predictions results were compared with experimentally obtained.

REFERENCES

MECHANICAL PROPERTIES OF A LAYERED FIBERCONCRETE STRUCTURE

A. Krasnikovs, V. Lapsa, V. Lusis, V. Zaharevsky, E. Machanovskiy, and G. Harjkova

1 Institute of Mechanics, Riga Technical University, LV-1658, Riga, Latvia
2 Concrete Mechanics laboratory, Riga Technical University, LV-1658, Riga, Latvia

Layered beams with different short fibers content in plies were fabricated. Beams were tested under four point bending conditions. Increasing applied load macro-crack is started at the bottom side of the beam. Material fracture process was modeled, based on single fiber pull-out laws, which were determined experimentally (for straight fibers, fibers with end hooks and corrugated fibers). For this purpose experimental program was realized and pull-out force versus pull-out fiber length was obtained (for fibers embedded into concrete at different depth and under different angle). Macro-crack is growing and opening. Position of a neutral line in a crack cross-section is changing, depending on the size of crack and was determined summarizing forces caring by fibers in crack opened part (chaotic and oriented fibers distributions in the plies were investigated. Monte-Carlo approach was used) and linear stress distribution in plies across the virgin part of the beam. In Fig. 1, position of the neutral line in two layers beam during macro-crack growth is shown.

Fig. 1. Stress and loads distribution in crack’s plane for two layers fiberconcrete beam.

Depending on a crack size and opening, different crack parts (along the crack) are bearing different load. As the load carried by each fiber at a constant crack opening is known from micro-mechanical investigations, the corresponding total bending load $P$ for a beam was obtained through equilibrium conditions. Modeling results were compared with bending experiments for beams consisting of one to five layers and different fibers content in plies. Prediction results were discussed. Model predictions were validated by 15×15×60 cm prisms four-point bending tests. Fracture surfaces analysis was realized for broken prisms with the goal to improve elaborated model assumptions.
THIN CONCRETE SHELLS REINFORCED WITH GLASS FIBERS. MANUFACTURING TECHNOLOGY AND MECHANICAL PROPERTIES

A. Krasnikovs1,2, V. Lapsa2, V. Lusis2, V. Zaharevsky1, and E. Machanovsky1

1 Institute of Mechanics, Riga Technical University, LV-1658, Riga, Latvia
2 Concrete Mechanics laboratory, Riga Technical University, LV-1658, Riga, Latvia

Pneumatic mould use is an approach with a set of advantages among thin wall structural element fabrication technologies. In the reported work, on the flat surface of a non-inflated pneumatic mould was imposed and smoothed down (forming a thin layer) glass fiberconcrete mix. Before concrete binding, mould was inflated by air forming a moderate curvature shell. After that, concrete was hardened, during concrete hardening air pressure in pneumatic mould was kept constant value. Then, an air in the pneumatic mould was blown out and shell was demolded. Two variants were observed: (a) shell is reinforced by uniformly distributed short glass fibers (concretes with three different fiber concentrations were investigated); (b) shell is reinforced by weft knitted glass fiber textiles (were fabricated in the laboratory). Simultaneously flat material samples were fabricated and experimentally tested. Composite materials elastic moduli as well as tensile strength were obtained. With the goal to predict mechanical behavior of produced thin fiberconcrete shells, a detailed micromechanical investigation for single fiber and few fibers bundle pull-out micro-mechanics was performed numerically (using FEM modeling) and experimentally. Macro-crack opening structural model, based on data sets with information about single fiber and few fibers bundle pull-out micro-mechanics, (was elaborated earlier [1]) was exploited predicting shell load bearing facility depending on opening of a crack in the loaded shell. Theoretical results were compared with the data obtained in experiments.

REFERENCES

DEFORMATION AND STRENGTH OF LAMINATED CARBON-FIBER-REINFORCED PLASTICS UNDER STATIC THERMO-MECHANICAL LOADING

N. K. Kucher, M. N. Zarazovskii, and E. L. Danil’chuk

G.S. Pisarenko Institute for Problems of Strength of the National Academy of Sciences of Ukraine, Kiev, Ukraine

The laws governing the deformation of laminated carbon fiber reinforced plastics (CFRP) produced using a carbon fiber tape LU-3 and epoxy resin ED-20M and their load-carrying capacity are investigated for two fixed values of the temperature (T=293 and 77K). In particular, the influence of the test temperature on the elasticity characteristics and the load-carrying capacity of unidirectional CFRP, and their laminates of various reinforcement schemes is studied under different modes of loading.

The composite is considered as an elastic orthotropic body which is under the conditions of plane stress state [1]. The Young’s modules $E_x$, $E_y$, the shear modulus $G_{xy}$, the Poisson’s ratio $\nu_{xy}$, the coefficients of thermal expansion (CTE) $\alpha_x$, $\alpha_y$, and also the appropriate strength parameters $\sigma_{tx}$, $\sigma_{-t}$, $\sigma_{xy}$, $\sigma_{-y}$, and $\sigma_{xy}$ were determined from the experiments. The above mentioned parameters were calculated using the results of tension; compression, out-of-plane bending and Iosipescu shear tests in accordance with the ASTM standards. A patented computational procedure [2] and a special device for dilatometer measurements were used to determine the CTE of CFRP in the temperature range $\Delta T = 77 \div 293 \text{K}$. The cooling of specimens down to the temperature of 77K was performed using liquid nitrogen.

The tests performed have made it possible to determine the ranges of variation in the mechanical and strength parameters in cooling down to the temperature of 77K [3]. In this case, the modules $E_1$, $E_2$, $G_{12}$ of unidirectional CFRP with fiber content 55% increase by 14.7, 9.8 and 18.2% respectively. The Poisson’s ratio $\nu_{12}$ can be considered as constant. The fracture stress $\sigma_{t1}$ increases by 4%, whereas $\sigma_{-1}$ decreases by 2.5%. The greatest changes were observed for the strengths in the transversal direction: the $\sigma_{t2}$ decreases by 37%, whereas $\sigma_{-2}$ increases by 48%. The shear strength $\sigma_{t2}$ also increases by about 26%. The CFRP laminates exhibit a low resistance to deformation in the direction normal to the plane of reinforcement and interlaminar shear at both room and cryogenic temperatures. An essential difference (by a factor of about 40) in the CTE in the transtropy directions results to significant thermal stresses, which value is depend on the CFRP operation temperature.

It is shown that the calculation of deformation and strength of laminated CFRP at cryogenic temperatures is necessary to consider thermal stress and temperature dependence of thermo-mechanical characteristics of the lamina.

The mathematical model for estimating the strength of laminated composites that takes into account the degradation of mechanical characteristics of the material after the “first ply failure” is proposed. The good agreement between the calculated and experimental data has been shown for composites with different combinations of stacking sequence of layers.

REFERENCES

EFFECT OF $\text{YBa}_2\text{Cu}_3\text{O}_{6.7}$ FILLER CONTENT ON THE PHYSICAL AND MECHANICAL PROPERTIES OF A POLYIMIDE COMPOSITE MATERIAL

A. I. Kupchishin, A. D. Muradov, and B. G. Taipova

Abai Kazakh National Pedagogical University, Republic of Kazakhstan

The mechanical tests of polyimide film and composite material with VTSP filler were performed on tensile testing machine of type S-TAR with speed of pushing the clamps 1.52 mm/min. The moving capture related with a measuring instrument did not exceed of 0.1 mm.

The tests were conducted in a uniaxial tension using a special reverse gear with a constant load and temperature $(20 \pm 2) ^\circ\text{C}$, relative air humidity $(45 \pm 5)\%$. The impact of mechanical stress produced up to a complete rupture of the samples. The breaking machine has been computerized and equipped with appropriate software as standard Windows applications.

The samples in the form of paralelepipid films were fixed with special clamps to the sliding mechanism. The working area of the films was 50 mm (length), 5 mm (width) and thicknesses: 35 mm in polyimide and composite materials in $(70 \div 85) \mu\text{m}$. The concentration $(C)$ of the fillers in the polymer matrix varied: $C = 0.05 \text{ mas.\%} ; 0.1 \text{ mas.\%}$ и $0.5 \text{ mas.\%}$.

It was established that low concentrations (up to $C = 0.1 \text{ mas.\%}$) cause a sharp decrease of plastic properties and increase the elastic properties of composite material. A further increasing concentration of filler leads to the stabilization of the plastic properties and a sharp decreasing in its mechanical properties of PCM (breaking stress decreases from 90 to 72 MPa). This effect of concentration of the filler on the mechanical properties of PCM is associated with a change in porosity of the material and structural activity of the filler relative to the polymer matrix. In such systems, relationship filler with the matrix by the boundary layer, influencing the physical and mechanical properties.
EFFECT OF GAMMA-RADIATION ON CHANGES IN THE REFRACTION OF “POLYIMIDE -YBa$_2$Cu$_3$O$_{6.7}$” COMPOSITE MATERIALS

A. I. Kupchishin, A. D. Muradov, B. G. Taipova, G. B. Sarsembayev, and B. A. Kozhamkulov

Abai Kazakh National Pedagogical University, Republic of Kazakhstan

Effect of gamma-radiation on the optical properties of polyimide film (PI) and its compositions with the filler YBa$_2$Cu$_3$O$_{6.7}$ of the various concentrations has been investigated.

The samples of polyimide composite materials (PCM) were prepared by the method of mechanical shifting followed by drying at the temperature 373 K. The finely crystalline powder YBa$_2$Cu$_3$O$_{6.7}$ with the size of particles 1-10 µm was used as a filler. The samples of PCM were polymer films with the concentrations of the filler C = 0.5% at thickness d = 75 µm, 0.1% at thickness d = 85 µm, 0.5% at thickness d = 82 µm. The net polyimide film with the thickness d=40 µm was taken as control sample.

The samples were irradiated at the room temperatures at RHM -γ -20 facility. The dose rate of $^{60}$Co -source was $1.6 \cdot 10^{-1}$ rad/sec and absorbed doses by samples were D=100, 250 and 600 kGy.

The samples optical parameters were measured by SPH -2000 spectrophotometer at the room temperature.

It was established that the refraction values n for PI-film smoothly increases at the doses of 150-250 kGy and sharp decreases at the dose of 600 kGy. The effect increasing of n values according to filler concentration and irradiation dose is observed in the PCM samples. The refraction for the concentrations up to 0.1 mas% is gradually increased and for C=0.5 mas.% the n value up to doses of 250 kGy is linearly increased and reached its saturation. The growth of PCM refraction is due to the fact that irradiation reduces the concentration of oxygen atoms in polyimide macromolecule structures and their number are increased in the boundary layer between filler and polymer matrix which reaches its saturation from the dose of 250 kGy.
COMPOSITE CONCRETE-FILLED TUBULAR MEMBERS IN TENSION

A. K. Kvedaras, A. Šapalas, and J. Katinas

Dept. of Steel and Timber Structures, Vilnius Gediminas Technical University, LT-10223, Vilnius, Lithuania

Dept. of Construction Maintenance, Educational University, Vilnius, Lithuania

Different composite structural members are widely used in the construction practice. Among them quite big interest is paid on the composite concrete-filled tubular members, especially as columns, beam-columns or beams. In framework of buildings or superstructure of bridges there are met also axially loaded structural members which sometimes are designed as composite ones too. Among such members may be mentioned composite concrete-filled tubular anchoring piles in foundations of harbour piers and special buildings, hangers of arch, suspension and cable stayed bridges, hangers of suspension floors in high-rise buildings, etc. Most effective composite concrete-filled tubular members are those, in which the circular steel shells are used, but these members may be also enough effective if the plastic or composite shells are applied. Sometimes the cores of such composite members may be done also from more effective than concrete materials – different composites. However, the behaviour of axially loaded composite concrete-filled tubular members is not investigated sufficiently. Therefore, not always all their possible efficiency may be gained or reliability safely satisfied.

This investigation deals with the composite concrete-filled circular steel tubular members under axial tension by analytical calculations, numerical and laboratory experiments. For comparison and application of data in the procedures of theoretical analysis such members under axial compression were investigated too. This paper deals also with the types of investigated members, their applicability and advantages compared to alternative structures. The methodology of design and evaluation of behaviour of composite members in tension is submitted because any recommendations exist in EC4 for composite steel and concrete members under tension.

In the full scale experimental part of the research the behaviour of composite members consisting of circular steel tubes filled with concrete under axial tension was investigated taking into account the interaction arising between the main components – circular steel tube and concrete core. A special attention was paid to bond and friction between the steel and concrete too. In the experiments simulating behaviour of composite concrete-filled circular steel tubular anchoring piles the limiting length of anchoring steel bars embedded in concrete core was investigated. Specimens were manufactured and tested in the laboratories of Civil Engineering Faculty of Vilnius Gediminas Technical University.

The composite concrete-filled circular steel tubular members were used also as a model object for simulation of behaviour of wider scale of composites, first of all when as an outer shell for the concrete-filled tubular members the plastic or composite tubes are used. For this simulation the numerical experiments on computer were carried out too.

Conclusions. Experimental load bearing capacity of concrete-filled members in tension increases in comparison with the pure steel tubular members. An assessment of these results with those obtained theoretically and by numerical analysis gives good agreement. It was experimentally determined the limiting lengths of anchoring the reinforcing bars through which the tension was supplied in concrete core not allowing slipping between concrete core and steel tube. Behaviour of composite concrete-filled circular polythene tubular members under axial tension was evaluated and compared with ones of members with circular steel outer shell.
SIMULATION OF THE MECHANICAL BEHAVIOR OF SANDWICH PANELS WITH A DENDROLIGHT® CELLULAR WOOD-MATERIAL CORE

E. Labans and K. Kalniņš

Riga Technical University, Institute of Materials and Structures, LV-1048, Riga, Latvia
E-mails: edgars.labans@rtu.lv, kaspars.kalnins@sigmanet.lv

In order to introduce a new type of sandwich panels with DendroLight® core a special attention must be paid for development of design practice capable in detailed representation of mechanical behaviour for cellular wood structure. A validation between detailed cellular core finite element analysis and experimental tests in bending and compression should lead to evaluation of design procedure for engineering design praxis [1]. Moreover computational time consumption makes it impractical to rely on the FE analysis exclusively, thus requiring a simple however reliable design tools and guidelines. The aim of this research is to create finite element model of sandwich panel with DendroLight® core, to match the mechanical behaviour of experimental bending and compression tests. Commercially available ANSYS FE code with parametrical inputs and shell elements has been selected for particular task. Transverse isotropic wood mechanical properties were assigned for a cellular wood frame and corresponding properties for plywood or MDF (medium density fibreboard) cover skins.

Fig. 1. Sandwich panel model and experimental 3-point bending test set up.

Special attention has been devoted to experimental testing of DendroLight® core structure and sandwich application. Bending and compression tests were performed on ZWICK Z100 testing machine. Bending set-up has been used to test sandwich beams with dimensions of 30×50×300 mm (Fig. 1). Compression tests were performed on specimens with dimensions 40×200×200 mm– according to EN789 standard [2]. For recording the strain distribution during the tests, the strain gauges alongside the non-contact optical measuring system ARAMIS has been used. Obtained accuracy of computer simulation model do not exceed 20% scatter comparing with experimental results within the elastic zone. Taking into account original scatter of wood mechanical properties it may be concluded as good basis for scaling up and delivering the design guidelines for the sandwich panel application with DendroLight® core.

REFERENCES
USE OF NANOPARTICLES OBTAINED FROM WOOD PROCESSING RESIDUES FOR REINFORCING PAPER

M. Laka, S. Chernyavskaya, A. Treimanis, and M. Skute

Latvian State Institute of Wood Chemistry, 27 Dzerbenes Street, LV-1006 Riga, Latvia

At present, the wood processing residues – chips and bark – are commonly used as a fuel. However, it would be more economically attractive to process those residues, so that they could be then used in composites with other materials to improve their properties.

In the present work, nanoparticles from wood processing residues obtained, were used as reinforcing fillers in paper sheets.

Paper sheets were produced from wood bleached sulphate pulp as well as from office and newsprint wastepaper. For obtaining nanoparticles, the following wood processing residues were used: birch sawdust, spruce shavings, and pine and grey alder bark. Non-extracted grey alder bark and that extracted in biorefinery were used. Those materials were destructed by a thermocatalytic method developed, and then dispersed in a water medium in a ball mill, obtaining gel-like dispersions that contained nanoparticles. These dispersions were dissolved and introduced in the paper furnish in different amounts. Nanoparticle content was 5-40% (from dry matter). The mechanical properties, water vapour sorption and swelling in water of the obtained paper sheets were investigated.

It has been found that, except pine bark, in all cases, with increasing filler content up to 20%, tensile index in the dry and wet state, and burst index increase. Thus, for example, at the 20% content of the nanoparticle filler from pine sawdust, spruce shavings as well as non-extracted and extracted grey alder bark, tensile index for paper sheets from sulphate pulp increased by 9, 12, 28 and 44%, and burst index by 20, 30, 78 and 90%, respectively. It can be seen that the greatest increase of mechanical indices is observed in the case of the nanoparticle filler from extracted grey alder bark. At the filler content above 20%, mechanical properties decrease again. Nanoparticle fillers from pine bark do not increase the mechanical indices of pine bark paper. The lower effect of the fillers is also on the paper sheets from newsprint waste paper and office paper.

Nanoparticle fillers from wood processing residues also slightly increase the barrier properties of paper. At the content of the filler from birch sawdust 20%, the water vapour sorption and swelling in water of the paper sheets decrease by 16% and 14%, respectively. The fillers from other wood processing residues decrease these indices to a lesser extent.

Thus, obtaining nanoparticles from wood processing residues, the former can be used as reinforcing fillers to improve the properties of paper.
CONTROL OF CONTACT ANGLE ON COMPOSITE SURFACE BY THERMAL EXPANSION

Ch. Lee and W. Hwang

Department of Mechanical Engineering, POSTECH, Pohang, Republic of Korea

For controlling the movement of a droplet on a surface, it is necessary to control its contact angle (CA). For deciding and controlling CA under atmospheric conditions, three factors are mainly considered: surface roughness, the surface energy of the liquid, and the surface energy of the solid surface, determined using Young’s, Wenzel and Cassie equations, respectively [1, 2]. Therefore, considerable research has been dedicated to developing methods of varying these factors for controlling the CA.

If roughness and surface energy of one surface are determined, we can predict CA by some equations. Therefore, CA will be controlled by changing roughness in this paper. Thermal expansion of solid will apply to control roughness. If there are two kinds of solid, their expansion rate by temperature should be different. It means that surface roughness will be changed according to temperature on composite which consist of two different materials. In addition, if two wetting characteristic are different (hydrophilic and hydrophilic), CA will be more rapidly changed by temperature because the surface directly contacted to droplet is changed.

We fabricated a composite surface whose wettability can be controlled by tuning the roughness and which shows a continuous contact angle (CA) gradient. The composite surface is composed of paraffin and anodic aluminum oxide (AAO), which have different coefficients of thermal expansion (CTE); hence the CA on the composite surface can be simply controlled by changing the temperature. The CA can rapidly change with temperature between hydrophilic and hydrophobic. Furthermore, we confirmed that the measured contact angles of the surface correspond with an equation for the apparent CA on the composite surface derived from the Cassie relation, Wenzel relation, and CTE.

REFERENCES


MECHANICAL TESTING OF PROTOTYPES OF ROAD SAFETY BARRIERS MADE FROM REINFORCED POLYETHYLENE

V. Leitlands and N. Viderkers

University of Latvia, Institute of Polymer Mechanics, 23 Aizkraukles st., LV-1006, Riga, Latvia

The replacement of existing metallic road safety barriers by barriers made from polymeric composite materials is beneficial both in terms of prices – the cost of fencing is significantly reduced, and durability the service life increases considerably.

The investigated material was a multilayer composite, based on a low-density polyethylene with various content of reinforcement in the form of a fiberglass fabric, mesh, or individual strands. According to standards\textsuperscript{1,2}, one of the most important characteristics of the material used for manufacturing road safety barriers is its tensile strength. The purpose of this work was to study the strength properties of the material and their evaluations in accordance with requirements of standards. The number of reinforcement layers in the composite was varied from one to four. Tension experiments were performed at a constant strain rate, with registration of the strength and elongation. The polyethylene reinforced with four layers of fibreglass exhibited a tensile strength of 178.5 kN, which corresponds to the fourth of ten possible resistance levels of road safety barriers.

The results obtained show that it is possible to use a glass-fiber-reinforced polyethylene in manufacturing road safety barriers. In the future, the employment of recycled raw polymeric materials can also significantly reduce the harm caused to the environment by polymeric waste.

REFERENCES

Linear axisymmetric vibrations of orthotropic circular cylindrical shells with cracks are analyzed. The main attention is focused on stepped circular cylindrical shells having circumferential cracks at re-entrant corners of steps. These cracks are considered as circular surface cracks with constant depth. Evidently, defects like cracks and flaws deteriorate the mechanical behavior of structural elements. The aim of the paper is to evaluate the influence of defects of this kind on the free vibrations of cylindrical shells made of elastic orthotropic materials. The changes of flexibility of the shell near cracks are prescribed by means of the compliance coupled with the stress intensity factor, which is known from the linear elastic fracture mechanics. In the present study, it is assumed that the surface crack is always open; the circumferential crack in the shell can be modeled as a distributed line spring. The presence of the crack in the shell causes a local flexibility, which is a function of the local dimensions and the elastic properties of the cracked region. The deformation in the cracked region can be described according to a compliance function. Problems related to the re-distribution of stresses and strains due to the extension of the crack are not treated herein. The influence of the circumferential cracks on the natural frequencies of the cylindrical shells is assessed numerically. Shells with various combinations of boundary conditions can be analyzed by the proposed method. The paper presents simple tools for the vibration analysis accounting for the influence of cracks located at re-entrant corners of steps and for the influence of elastic characteristics of an orthotropic material in various directions. Numerical results are presented for one- and two-stepped shells.

REFERENCES

THE DEVELOPMENT OF KNIFE- AND BULLET-IMPACT-RESISTANT COMPOSITE STRUCTURES

A. A. Levinsky, S. B. Sapozhnikov, and T. S. Grass

Department of Physics, South Ural State University, 454080, Chelyabinsk, Russia

Existing full-fabric armor vests (NIJ standard - 0101.06, USA) can resist high velocity impacts of small gun bullets successfully, but it cannot provide any pointed or sharp-edged weapon (stab) attacks protection even at first protection level (NIJ standard - 0115.00). There are only inserts for stab protection on the armor vest's market.

In this study, two ways of full-fabric armor enhancement were considered. First: pack of layers of aramid fabric covered by suspension of alumina micro- and nanoparticles; and second: laminated composite structures made of modified polycarbonate.

An experimental investigation of low velocity stab resistance characteristics of aramid fabrics covered by thin layer of alumina micro- and nanoparticles was done. This layer increases a coefficient of friction inside of ballistic aramid fabric and with steel also. Alumina particles effectively blunts a sharp edge of knife. Such modification of typical Twaron 709 fabric can 5 times ups the puncture force of standard 'Spike' weapon. Herewith the areal density of fabric increased only by 10 – 12 %. It should be noticed, that there are no significant increasing of 'Edged blade P1' cut resistance. Ballistic characteristics of this fabric no changed practically.

It was shown the opportunity of increasing stab resistance of covert full-fabric armor vests by laminated composite structures based on polycarbonate plates as a semi-hard inserts. Such inserts provides effective combined protection from small firearm and sharp-edged/pointed weapons.

Mechanical properties of polycarbonate at various strain rates have determined. An experiment for cut resistance force determination at quasi-static loading by edged-blade P1 knife of original polycarbonate plates and modified ones by aramid fabric layer has executed. Several aramid fabrics were pressed in wetted by chloroform back surface of polycarbonate plates. Such composite structure was based on idea of increasing the compressed length of knife blade due to local plate bending around impact point. Use the polycarbonate plate thickness of 5 mm and only one Twaron 709 fabric backing can 30% increase of bending stiffness and 35% increase of cut energy. This is proved by quasi-static and drop-mass tests.

An ability to work at repeating impacts on composite plates was studied. Digital image correlation method for strain field investigation of plate with defects under tension was used. This analysis showed that second impact can be targeted to the point located at the 25 mm or more from previous point with the same stab resistance. FEA modeling confirmed this result.

At the final stage the modified polycarbonate plates were impacted by high velocity steel balls (dia. 8 mm). This experimental procedure showed that such composite plates effectively work with them for loss of ball velocity from 300–350 m/s down to 100–150 m/s. In this case it is possible to use much less fabric layers in the ballistic part and reduce overall cost of protective vest.
IMPACT ESTIMATION OF EXTERNAL ACTUATING FACTORS AND OPERATIONAL CONTAMINATION ON THE OPERATIONAL CAPABILITY OF FIBROUS POLYMER COMPOSITE MATERIALS.

D. Lobanov¹, V. Vildeman¹, A. Babin², and M. Grinev³

¹State National Research Polytechnical University of Perm, Perm, Russia
²The Ural Scientific Research Institute of Composite Materials, Perm, Russia
³Aviadvigatel OJSC, Perm, Russia

The aim of this work is investigation of mechanical properties of fiberglass (GFRP) and carbon fiber (CFRP) reinforced plastics with standard flat specimens under shear and bend loading before and after external actuating factors were applied; research of physical-mechanical properties of sandwich panels with a tubular filler made from GFRP and CFRP under tension and compression loading before and after special environments were applied.

Groups of GFRP and CFRP specimens were soaked in water, oil, gas, hydraulic fluid and Nefras. This work contains analysis of impact contaminants environments on the mechanical properties of polymer fiber composite materials and structures. The methodological issues of using modern test equipment for studying the properties of composite materials and structures were considered. Tests were carried out on the universal electromechanical test system Instron 5882 [1].

The work presents results of mechanical tests of GFRP and CFRP specimens: transverse bending and interlaminar shear (short beam method), sandwich panels under tension and compression loading [2]. The effect of external polluting operating on mechanical properties of polymer fiber composite materials and structures was estimated. Stress-strain diagrams were obtained in tests.

REFERENCES


IMPROVING THE STRUCTURAL PERFORMANCE OF ADVANCED COMPOSITES WITH NON-CONVENTIONAL LAMINATES

C. S. Lopes¹, Z. Gürdal², and P. P. Camanho³

¹IMDEA Materials Institute, Madrid, Spain
²Delft University of Technology, The Netherlands
³University of Porto, Portugal

Traditionally, the design possibilities offered by composite laminates have been almost entirely narrowed to quasi-isotropic configurations due to their close behaviour to monolithic materials and easily predictable response. In a few applications, orthotropic laminates are used, but historically confined to combinations of 0°, 90° and ±45° ply angles due to the easiness of design and manufacturing by traditional methods. However, as composites become the main aeronautical materials, the industry is turning to completely automated systems capable of rapidly manufacturing large and high quality composite parts. An example is the fuselage of the new long haul Boeing 787 aircraft being built in sections by means of Automated Fibre-Placement (AFP) machines. With the same effort, these highly precise systems can build laminates made of combinations of plies at angles other than the conventional ones. This allows the dispersion of the fibre angles and avoidance of ply clustering. Furthermore, AFP machines can place fibre tows in a steered fashion, resulting in laminates whose elastic properties vary along planar coordinates. Such structures are termed Variable-Stiffness Panels (VSPs).

Studies show that the buckling load of composite panels can be increased by using dispersed laminates. Their great promise is, however, in the improvement of damage resistance [1].

The in-plane stiffness variation allowed by fibre-steering demonstrated a great capacity for load redistribution from the central sections of the panels to their supported edge sections, allowing for more than doubling the buckling loads as compared to the most efficient straight-fibre designs with the same mass [2]. The advantages in terms of strength performance are also remarkable, with demonstrated improvements well above 50% [2]. Furthermore, due to potential for the load redistribution, it is possible to design VSPs that do not develop critical stress concentrations around central holes and can actually be insensitive to them in terms of buckling and failure loads [3]. This is a remarkable achievement and a great promise regarding weight savings in comparison to conventional solutions where the thickness is typically increased to mitigate the effects of stress concentrations around cut-outs, e.g. aircraft windows and doors.

A summary of the possibilities allowed by non-conventional composite structures is made in this presentation. Directions along which current research work is being performed are given.

REFERENCES


APPLICATION OF ELECTRONIC SPECKLE PATTERN INTERFEROMETRY (ESPI) TECHNIQUE FOR DAMAGE CHARACTERIZATION IN LAMINATES

M. S. Loukil\textsuperscript{1,2} and Z. Ayadi\textsuperscript{2}

\textsuperscript{1}Division of Materials Science, Luleå University of Technology, SE-971 87 Luleå, Sweden
\textsuperscript{2}Institut Jean Lamour, EEIGM 6 Rue Bastien Lepage, F-54010 Nancy Cedex, France

Composite laminates under service loading undergo complex combinations of thermal and mechanical loading leading to microdamage accumulation in plies. The most common damage mode is intralaminar cracking. The crack opening displacement (COD) and the crack sliding displacement (CSD) during loading reduce the average stress in the damaged layer, thus reducing the laminate stiffness. In other words, the elastic modulus in the loading direction and the corresponding Poisson’s ratio decrease.

These parameters depend on material properties of the damaged layer and surrounding layers, on layer orientation and thickness. Previously these parameters have been calculated using finite element method (FEM) assuming linear elastic material with idealized geometry of cracks [1]. The only correct way to validate these assumptions is through experiments.

The main objective of this paper is to measure these parameters for different laminate lay-ups in this way providing models with valuable information for validation of used assumptions and for defining limits of their application.

In particular, the displacement field on the edges of a [0/70\textdegree/-70\textdegree\textsubscript{s}]\textsubscript{s} and [0/55\textdegree/-55\textdegree\textsubscript{s}], glass fiber/epoxy laminate specimens with multiple intralaminar cracks is studied and the COD dependence on the applied mechanical load is measured. The specimen full-field displacement measurement is carried out using ESPI (Electronic Speckle Pattern Interferometry) [2, 3]. ESPI is an optical technique that provides the displacement for every point on a surface and offers the possibility to measure both, the in-plane and out-of-plane displacement without surface preparation.

The displacement jumps corresponding to cracks are clearly visible and can be used to determine the opening displacement along the cracks. The effect of crack interaction on the COD at high crack density is also investigated.

REFERENCES

THERMO-ELASTIC PROPERTIES OF NON-UNIFORMLY DAMAGED LAMINATES AT HIGH CRACK DENSITY

M. S. Loukil\textsuperscript{1,2}, J. Varna\textsuperscript{1}, and Z. Ayadi\textsuperscript{2}

\textsuperscript{1}Division of Materials Science, Luleå University of Technology, SE-971 87 Luleå, Sweden
\textsuperscript{2}Institut Jean Lamour, EEIGM 6 Rue Bastien Lepage, F-54010 Nancy Cedex, France

Intralaminar cracking in laminates is the most typical mode of damage in tension. Due to this kind of microdamage the laminate undergoes stiffness reduction. Stiffness reduction simulation in damaged laminates is usually performed assuming that cracks are equidistant and crack density is the only parameter needed [1]. However, the crack distribution in the layer may be highly non-uniform as schematically shown in Fig. 1, especially in the initial stage of multiple cracking.

The earlier developed model for general symmetric laminates is generalized to account for non-uniform crack distribution. Parameter $K$ is introduced as the ratio $K = \frac{2l}{1+d}$ to characterize the non-uniformity of the spatial distribution (Fig. 1).

In parametric analysis, the axial modulus of cross-ply laminates with cracks in internal and surface layers is calculated. Fig. 2 shows that the axial modulus reduction is the lowest if cracks have uniform distribution ($K = 1$).

A “double-periodic” approach is presented to reduce the non-uniform case to the average of solutions for two periodic crack systems. It is very accurate for cracks in internal layers, whereas for high crack density in surface layers it underestimates the modulus reduction.

REFERENCES

FABRICATION OF A SUPERHYDROPHOBIC SURFACE HAVING DRAG REDUCTION EFFECTS

S. Lyu¹, D. C. Nguyen², B. S. Yoon², and W. Hwang¹

¹Dept. of Mechanical Engineering, Postech, Pohang, Korea
²School of Naval Architecture & Ocean Engineering, University of Ulsan, Ulsan, Korea

Superhydrophobic surfaces have been studied for many years because of the advantages of the surface such like drag reduction, self-cleaning and anti-fouling effects. Lotus leaves are the most well-known superhydrophobic surfaces and many techniques were developed to mimic bio hierarchical structures of lotus leaves. In this paper, simple, fast and cheap fabrication method of superhydrophobic surface using anodizing and SAM (self-assembly monolayer) coating treatment was reported. And drag reduction experiment was conducted to confirm the property of the surface.

Two factors of material’s wetting property and surface structure are important in superhydrophobic surfaces. The surface energy of the surface determines wetting property of the surface. When there is micro or nano scale structures on the surfaces, roughness of the surface maximize the surfaces’ wetting property. From the equation of Bico et al,

\[ \cos \theta_A = \alpha \cos \theta_f - (1 - \alpha) \]

Therefore, wetting property and hierarchical structure should be obtained to get superhydrophobic surface.

Firstly, aluminium plate was prepared and anodized in oxalic acid. Usually during anodizing, arranged holes are appeared on the aluminium surface. But with high voltage, holes on the aluminium pipe surface started to merge each other. Nano scale pillars were generated by anodizing. Empty spaces where holes merged and group of nano pillars made hierarchical micro/nano structures on the aluminium surface. Anodized aluminium plate was then treated with HDFS solution. Plate was immersed in the HDFS solution mixed with hexane in the ratio of 1:1000. After rinse the surface with hexane for 20 minutes, the plate was dried at room temperature for 24hrs. HDFS coated surface was superhydrophobic property and static contact angle of coated surface was 160°. Drag reduction experiment was conducted in the water channel. In the laminar flow, drag force of the superhydrophobic surface was maximum 50% of the normal aluminium plate.

Fig. 2. Fabrication process and contact angle of superhydrophobic surface.
NONLOCAL ELASTICITY APPROACH TO THE VIBRATION ANALYSIS OF GRAPHENE SHEETS

J. Majak\textsuperscript{1}, M. Pohlak\textsuperscript{1}, M. Eerme\textsuperscript{1}, K. Karjust\textsuperscript{1}, and J. Kers\textsuperscript{2}

\textsuperscript{1}Dept. of Machinery, Tallinn University of Tech., Ehitajate tee 5, 19086 Tallinn, Estonia
\textsuperscript{2}Dept. of Mat. Eng., Tallinn University of Tech., Ehitajate tee 5, 19086 Tallinn, Estonia

Graphene is defined as a flat monolayer of carbon atoms tightly packed into a two dimensional (2D) honeycomb lattice. Study of graphene is a new emerging research area due to its superior mechanical, electrical and thermal properties. Graphene is used for the development of superconducting devices for micro-electromechanical system (MEMS), nano-electromechanical system (NEMS) applications, nanocomposites and nano-optomechanical systems, etc.

The modelling for the nanostructures is classified into three main categories: atomistic, hybrid atomistic-continuum mechanics and continuum mechanics approaches. The atomistic and hybrid models are computationally more expensive than continuum mechanics models.

In the current study a continuum model based on nonlocal elasticity theory has been treated for graphene sheets. According to nonlocal elasticity the stress state at a given point is dependent on the strain states at all points in the body. The nonlocal elasticity theory has been introduced by Eringen and Edelen in integral form \cite{Eringen1} and got little attention due to its complexity. An equivalent expression of the nonlocal stress in a differential form was given by Eringen in \cite{Eringen2}.

\begin{equation}
(1-\eta \nabla^2)\sigma_{nl} = \sigma^l. 
\end{equation}

In Eq. (1) $\sigma_{nl}$ and $\sigma^l$ stand for nonlocal and local stress tensors, $\eta$ is the nonlocal parameter and $\nabla^2$ is Laplacian operator in Cartesian coordinate system. Most commonly classical plate theory (CLPT), first order shear deformation theory (FSDT) is applied for modelling strain-displacement relations. However, it is known that CLPT and FSDT are inadequate for accurate analysis nanostructures and higher order plate theory is required for accurate predictions of the structural behaviour \cite{Ansari}. In \cite{Ansari, Pradhan} third order plate theory and nonlocal elasticity is applied for obtaining field equations.

In the current study the field equations for vibration analysis of the graphene sheet are derived in more general form proceeding from geometrically nonlinear approach for strain-displacement relations. The proposed approach covers the field equations for graphene sheet with geometrically linear strain-displacement relations as a particular case.

REFERENCES

DETERMINATION OF MICRO-CRACK PATH IN PARTICULATE COMPOSITE

Z. Majer¹, P. Hutař², and L. Náhlík²

¹Brno University of Technology, Faculty of Mechanical Engineering, Czech Republic
²Institute of Physics of materials AS CR, Dep. CEITEC IPM, Czech Republic
majer@fme.vutbr.cz

The main objective of this paper is the numerical investigation of fracture behaviour in polymer particulate composites. The polymer particulate composites are frequently used in many engineering applications due to the possibility of modifying the global mechanical properties of the resulting composite [1]. In this paper the composite is modelled as a three-phase continuum. Numerical model of composite is composed of matrix, particle and interphase.

The interphase is created on particle-matrix interface. The presence of mineral fillers usually causes a cure reaction between particles and matrix and finally results in the formation of this third phase. In addition, the mineral fillers are usually chemically treated to reach better dispersion in the polymer matrix and this process has positive effect on formation of interphase with proper properties.

The interphase thickness can be estimated indirectly from the macroscopic composite properties. In relation to the used method of estimation it can result in a huge spectrum of thickness values, varies from 0.012 to 0.160 µm. According to contribution [2], where the interphase thickness is correlated with the work on adhesion, the interphase thickness is estimated as 0.1 µm.

The computational model is created with respect to the following general terms [3]: (i) particles should be of small size (less than 5 µm), (ii) the aspect ratio must be close to unity to avoid high stress concentration, (iii) the particles must debond prior the polymer matrix reaches the yield strain in order to change the stress state of the matrix material and (iv) particles must be dispersed homogeneously in the polymer matrix.

In the previous study [4], the composite was modeled in terms of linear matrix. In this paper the non-linear material model of matrix is used in numerical calculations. The interaction of micro-crack and particle in the full range of polymer particulate composite is studied. Only the particles placed close to the micro-crack tip significantly influence micro-crack behaviour. Therefore, the computational model is for simplification reduced to four particles and the micro-crack is located among the particles.

REFERENCES

FEATURE-BASED METHOD IN THE APPLICATION OF STRUCTURAL COMPOSITES - EXPERIMENTAL SYNTHESIS AND ANALYSIS

**M. Majzner and A. Baier**

Silesian University of Technology, The Faculty Of Mechanical Engineering, Institute of Engineering Processes Automation And Integrated Manufacturing Systems, 44-100, Gliwice, Poland

For several years, there is a trend to use object-oriented methods (Feature Modeling) to design issues. Commonly applied to modeling using object oriented methods - Feature Based Modeling. In this study, a systematic and formalized features in the context of modeling and of manufacturing structural objects created on the basis of structural fiber composites is proposed.

The research presented in this paper, are a development of the research on application of features method in computer aided design, construction, manufacturing of structural objects. In previous work was defined sets of features: construction features, technological features, functional features, information features.

In the paper, features, determining designing phases of composites materials and structural objects made of their application were defined. At a basic level of material was defined features - which in fact features information having information on material properties of components-phases of the composite. Defined in this way MOE² and MOEᵐ, respectively symbolize the reinforcement and the matrix phase. At this level, the two phases operate as independent elements. Going to the next level, it is formed a complex feature, called a composite feature COE, formed in the technological process of connection, of simple feature MOE. It represents a single layer of a composite made up of at least two phases, having an additional parameter of the design feature - the thickness. In turn it is defined master feature (feature laminate LOE), which is built from many COE, creating a composite layered. Thus, created composite object attached to a structural allows one to perform stress analysis, using field methods (such as FEM) of specific materials recipe.

Synthesis of research conducted to find a configuration that allows the replacement of cover material made of sheet steel, the composite having mechanical properties and strength, the same or better than the standard material. Conducted research on the selection of components, the orientation of fibers in each layer and the number of layers. In the first stage number of studies using glass fabric of various weights was carried out (Tab.1.).

Table 1. Examples of results

<table>
<thead>
<tr>
<th>No.</th>
<th>Material</th>
<th>Max displ., mm</th>
<th>Max.stress, MPa</th>
<th>Thickness, mm</th>
<th>Weight, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steel plate 2 mm</td>
<td>58.13</td>
<td>63.55</td>
<td>2</td>
<td>15.66</td>
</tr>
<tr>
<td>2</td>
<td>Steel plate 0.5 mm, 1 layer of glass fiber 450g/m²</td>
<td>1579.07</td>
<td>563.38</td>
<td>0.98</td>
<td>4.81</td>
</tr>
<tr>
<td>5</td>
<td>Steel plate 0.5 mm, 4 layers of glass fiber 450 g/m²</td>
<td>183.04</td>
<td>244.76</td>
<td>2.42</td>
<td>7.52</td>
</tr>
<tr>
<td>6</td>
<td>Steel plate 0.5 mm, 1 layer of glass fiber 1000 g/m²</td>
<td>674.07</td>
<td>397.48</td>
<td>1.45</td>
<td>5.7</td>
</tr>
<tr>
<td>9</td>
<td>Steel plate 0.5 mm, 4 layers of glass fiber 1000 g/m²</td>
<td>42.10</td>
<td>129.83</td>
<td>4.3</td>
<td>11.04</td>
</tr>
</tbody>
</table>

Acknowledgements. This work has been conducted as a part of research project 2011/01/N/ST8/07406, supported by The National Science Centre, Poland, 2012-2013.
ULTRASTRONG/TOUGH CONTINUOUS DNA NANOFILAMENTS FOR NOVEL HIERARCHICAL BIOMATERIALS AND COMPOSITES

K. Maleckis and Yu. Dzenis

Department of Mechanical and Materials Engineering, Nebraska Center for Materials and Nanoscience, University of Nebraska-Lincoln, Lincoln, NE 68588-0526 USA
e-mail: ydzenis@unl.edu

One-dimensional DNA structures can be used as building blocks and templates in advanced bionanotech materials and devices. So far, such structures have been produced by bottom-up self-assembly methods as discontinuous nanofibers and networks. Continuous 100% DNA nanofibers were produced in this work using top-down electrospinning method. Nanofiber diameters were varied in the range from 50-500 nm by changing process parameters. Individual nanofibers were mechanically tested through failure using specially developed testing protocol. Significant improvement of nanofiber strength was observed with the decrease of nanofiber diameter while strain at failure remained constant within the experimental error. Stress-strain curves of individual nanofibers exhibited inverse S-shape and toughness of DNA nanofibers far exceeded the toughness of the best structural fibers such as carbon or Kevlar and approached the values of toughness for best spider silks. In addition to the double stranded (ds) DNA, nanofibers from single stranded (ss) DNA solutions were also prepared by a modified process. Mechanical testing of the ssDNA nanofibers exhibited qualitatively different scaling. In particular, strain at failure of the ssDNA nanofilaments increased with the decrease of their diameter. The highest strength values recorded were on the par with the strength of commercial reinforcing fibers while toughness far exceeded commercial fiber performance. The measured nanofiber strength also exceeded the published single DNA molecule strength by 4.5 times. Short range structural studies confirmed the conformational differences between the dsDNA and ssDNA nanofibers and the source DNA. Raman spectra revealed shifts of sugar-phosphate backbone and basepair vibrations peaks indicating possible transformations from B to A and Z duplexes in the dsDNA and ssDNA nanofibers. The observed unusual ultrahigh mechanical performance of DNA nanofilaments, coupled with recently demonstrated precision-assembly of nanofilaments into controlled 1D, 2D, and 3D constructs, open up new exciting opportunities in DNA nanotechnology and high-performance hierarchical biomaterials and composites.
Composite materials are an important and growing material group in a large number of industries such as aeronautics, marine, automotive, energy production and infrastructure. The most common composite materials is manufactured from fibres such as glass fibres and carbon fibres together with oil based resins i.e. polyester, vinyl ester and epoxy. An increasing use calls for alternative environmental friendly, biobased, constituents. The new biobased materials have not only to compete in mechanical properties but it also has to restrain environmental loads like moisture and temperature over time.

In the present work, the predictions of the long term properties of biobased resins are made. The work also presents the influence of moisture, comparison with creep test data and comparison with oil based resin. The long term property prediction is made by using dynamic mechanical thermal analysis, DMTA, measurements and time temperature superposition, TTSP, [1, 2]. The procedure is to make DMTA measurements in three-point bending mode of the storage modulus at different frequencies at increasing temperature. The method used in this case was to measure the modulus at 0.1, 0.3, 1, 3 and 10 Hz at temperatures 25 – 175°C with 5°C intervals. The frequencies were then transformed to time by Eq. (1) below

\[ t = \frac{2}{\pi \omega} \]  

where \( \omega \) is the frequency. Reference temperature were chosen 25°C, as well as all other curves were shifted horizontally creating a continuous master curve. The modulus time master curve was then inverted creating creep compliance time master curve. This curve is compared to creep test. The moisture behaviour is characterised in form of water uptake, change in glass transition temperature, \( T_g \), and change in dynamic response. The water uptake is determined by submersion into water and tracking the weight change over time. The glass transition temperature is determined in DMTA by conducting a temperature sweep at constant frequency. The change in \( T_g \) is used as a knock down factor and a vertical shift of the master curve. An attempt to determine the dynamic response of wet samples has also been made with the insight that higher temperatures will dry the sample during testing leading to a non homogenous moisture distribution within the sample. The results of the study show on differences between TTSP and creep data. It also shows the differences between different biobased resins and a comparison to oil based epoxy.

**REFERENCES**

METHOD OF INVESTIGATION OF LAYERED COMPOSITES WITH INTERPHASE IMPERFECTIONS AND DAMAGED LAYERS

M. Marchuk\textsuperscript{1}, V. Kharchenko\textsuperscript{2}, and M. Khomyak\textsuperscript{3}

\textsuperscript{1}Pidstryhach Institute for Applied Problems of Mechanics and Mathematics, NASU, L’viv, Ukraine
\textsuperscript{2}Yuzhnoye Design Office, Dnipropetrovs’k, Ukraine
\textsuperscript{3}Ivan Franko National University, L’viv, Ukraine

Design and investigation of layered composites required the construction of adequate mathematical models for their stress-strain state and creation on this base an effective method of calculation, because stress distribution in such objects significantly depends on the conditions of interaction between phases. Classic hypotheses on the ideal interlayer contact preferably far from reality, because presence delaminating, zones of weak adhesion at the interfaces and damages the main phase-layers, which can be both as technological and exploitation origin. The presence of such imperfections can be given only at discreet consideration by thickness specified composites. In the proposed report, interlayer damages models the jump of displacements, and damage to the main layers are considering only those with piecewise continuous displacement field.

A layered structure is considered, each component of which is modeling by thin shells. The stress-strain state of shell is described by equations of refined theory [1]. Functional of equivalent variation problem, where the contributions of damages on the contact surface by separate term is selected, is written. The theorems of dual and existence, and unity of solution are reduced. The independent finite element approximation of generalized displacements defined on the middle surface of layers and interlayer contact stresses are proposed. This is essence a new mixed scheme of finite element method. As a result, the problem is reduced to finding the solution of linear algebraic equations of block type. For its solving the specialized block algorithm is elaborated.

For general cases of indeterminate boundaries of damage domains, which arise about excess permissible level by contact stresses, iteration algorithm its determination is constructed. The convergence of the iterative process is proved.

The proposed method is tested on the test problems. With this method the solutions of new bending problems of three-layer plate with in the boundary region of plastic slip and two-layer plates in the presence of interlayer defects and damage of layer are obtained. The influence of the presence of defects on the deformability and the distribution of interlayer contact stresses compared to their absence are investigated.

REFERENCES

FREE VIBRATIONS OF A TWO-LAYERED PLATE-STRIP WITH COMPOSITE COMPONENTS PLIABLE IN TRANSVERSE SHEAR AND COMPRESSION

M. Marchuk\textsuperscript{1}, V. Pakosh\textsuperscript{1}, and O. Lesyk\textsuperscript{2}

\textsuperscript{1}Pidstryhach Institute for Applied Problems of Mechanics and Mathematics, NASU, L’viv, Ukraine
\textsuperscript{2}Ternopil’ National Economic University, MESU, Ternopil’, Ukraine

Composite plates of layered structure (especially two-layered) with regulated characteristics of strength and material consumption are the most commonly used support elements of constructions and hardware for different purposes. In most cases, they are subjected to intense dynamic (including cyclic) loading. Therefore, the accurate estimation of such dynamic characteristics as the spectrum of natural frequencies is topical problem on their designing in order to prevent resonance phenomena under operational conditions.

The most typical peculiarity of deformation of thin-walled elements with modern reinforced polymer-based composites (both in static and dynamic cases), together with anisotropy of elastic characteristics is the pliability to transversal shear and compression. It should be noted that today in the literature there are few papers on the study of oscillations of composite plates, with simultaneous taking into account the pliability to the transversal shear and compression, especially for their layered structure along the thickness in discrete consideration of layers. The prevailing majority of results are obtained by numerical methods. In the proposed report on the base of a variant of refined theory of plates, taking into account explicitly the pliability to transversal shift and implicitly – to compression, a mathematical model of free vibrations process of two-layer plate-strip with the discrete consideration of components of such structures is proposed. The analytical expressions for the spectrum of natural frequencies of two-layer plate-strip with hinged elongated edges on the lower face plane of structure are obtained. The influence of physical and mechanical properties and geometric parameters of the components of structure on the magnitude of values of natural frequencies is analyzed. As a special case, the expression for the spectrum of natural frequencies of free vibrations of plate-strip with thin protective coating on the front upper surface is obtained.
INTERFACIAL FAILURE IN COMPOSITES UNDER OFF-AXIS LOADING

Ch. Marotzke

BAM - Federal Institute for Materials Research & Testing, Division 5.3 - Mechanical Behaviour of Polymers, D-11205, Berlin, Germany

Common strength criteria for composite materials are either based on pure stress interaction functions with no reference to the actual failure process or on the discrimination in only two failure modes on the global level. This is, common failure criteria are not based on micromechanical failure processes. As well known, e.g. the first ply failure in laminates is caused by transverse stresses, causing a debonding of the fibers. The bond strength and the process of interfacial failure accordingly govern the failure of the lamina.

In the first part of this paper, the strength of the fiber-matrix interface under combined radial and longitudinal shear stresses is investigated. A model system is used consisting of single fibers embedded in small tensile specimen, specially designed to avoid failure due to stress concentrations at the fiber ends. In order to study the failure of the interface under mixed-mode conditions, the fibers are arranged under various off-axis angles. The debonding process of the interface is observed under a microscope. A basic failure criterion for the fiber/matrix interface is developed based on the experimental data.

In a second part, the failure inside a lamina under transverse loading is studied by finite element analyses on a model composite. This is comprised of a 12-fiber hexagonal array in terms of a representative cell. The energy release rate for an interface crack propagating circumferentially around the central fiber under transverse loading is analysed. Since the crack faces come into contact during crack propagation, contact elements are provided. The mode I and mode II parts of the energy release rate are given. The dependence of the energy release rate on the fiber volume fraction is studied on volume fractions between 5% and 85%.

It appears that the first phase of the crack is dominated by mode I stresses. The total energy release rate as well as the mode ratio dramatically changes during crack propagation. This effect strongly increases with growing fiber volume fraction. The increasing energy release rate indicates that the first phase of crack propagation is unstable. It is followed by a mode II dominated, stable crack propagation. The dominating failure mode strongly depends on the fiber volume fraction. That is, even though the interfacial failure is similar to that observed in the single fiber experiments, the influence of the neighbouring fibers is essential.

Fig. 1. Mode I, mode II and total energy release rate of circumferential interface crack.
PARTICULATE COMPOSITE MATERIALS: NUMERICAL MODELLING OF CROSS-LINKED POLYMER REINFORCED BY ALUMINA BASED PARTICLES

B. Máša$^{1,2}$, L. Náhlík$^{1,2}$, and P. Hutař$^{1,2}$

$^1$Dep. CEITEC IPM, Institute of Physics of Materials, Academy of Sciences of the Czech Republic, Žižkova 22, 616 62 Brno, Czech Republic

$^2$Faculty of Mechanical Engineering, Brno University of Technology, Technická 2 616 69 Brno, Czech Republic

The contribution deals with estimation of macroscopic mechanical properties of particulate composite under tensile loading. Composite studied consists of polymer matrix in a rubbery state (polymethylmethacrylate - PMMA) and alumina based particles (Al$_2$O$_3$). Numerical modelling based on the finite element method (FEM) was performed to determine stress-strain behaviour of polymer composite. Numerical simulations took into account hyperelastic properties of cross-linked polymer matrix, described by the three parameter Mooney-Rivlin material model [1]. Representative volume element (RVE) model was chosen for FE analyses as a model of a microstructure of the composite. Various compositions of particles, their different shape and orientation have been considered. Various orientation of loading of RVE has also been investigated. Progressive damage model, based on the cohesive zone, has been implemented to the numerical models.

![Fig. 1. Geometric models of particulate composite using the RVE for volume fraction of particles 17.3% (30 wt. %).](image)

The mechanical properties obtained from computations, which included damage model, have been compared with experimental data and good agreement has been found. The procedure presented can be used for estimation of mechanical properties of new particulate composites with cross-linked polymer matrix and contributes to the clarification of damage development and failure of studied type of particulate composite.

**Acknowledgment:** this work was supported through the Specific academic research grant of the Ministry of Education, Youth and Sports of the Czech Republic No. FSI-J-11-38 provided to Brno University of Technology, Faculty of Mechanical Engineering.

**REFERENCES**

DETERMINATION OF STRESS-CRACK OPENING RELATIONSHIP OF SFRC BY INVERSE ANALYSIS

A. Meskenas¹, G. Kaklauskas¹, V. Gribniak¹,², D. Bacinskas¹, and V. Gelazius¹

¹Department of Bridges and Special Structures, Vilnius Gediminas Technical University (VGTU), Vilnius 10223, Lithuania
²Department of Strength of Materials, VGTU, Lithuania

Quantifying the residual stresses \( \sigma_{fr} \) in tension is one of the most critical issues in the theory of steel fibre reinforced concrete (SFRC) [1]. Present investigation is aimed at determination of the stress-crack opening (\( \sigma_{fr}-w \)) relation of SFRC. The inverse technique was proposed for determination of residual stresses employing the experimental data from three-point bending tests on notched members as shown in Fig. 1. A nonlinear finite element analysis program ATENA was utilized to verify the obtained stress-crack opening (\( \sigma_{fr}-w \)) relation. Simulated load-crack mouth opening displacement (P-CMOD) curve was compared with the experimental data (Fig. 1.) validating adequacy of the proposed technique.

![Fig. 1. Derivation and verification of stress-crack opening relation of SFRC.](image)

REFERENCES

ACRYLONITRILE BUTADIENE STYRENE/HIGH DENSITY POLYETHYLENE COMPOSITES FROM WASTE SOURCES BY USING COUPLING AGENTS

N. Miskolczi¹, V. Sedlarik², P. Kucharczyk², and H. Szakacs¹

¹University of Pannonia, Faculty of Engineering, Institute of Chemical Engineering and Process Engineering, MOL Department of Hydrocarbon & Coal Processing, H-8200, Veszprém, Egyetem u. 10, Hungary
²Tomas Bata University, Faculty of Technology, Polymer Centre, Zlin, Nám. T.G. Masaryka 275, 76272 Zlin, Czech Republic

Acrylonitrile butadiene styrene is one of the mostly used engineering plastics, while polyethylene is the mostly used mass plastics with advanced properties. ABS and HDPE establish immiscible blends, which lead to bad morphology and poor mechanical properties in the products. The problem occurred by the mentioned incompatibility should be solved by the applying of coupling agents, which are able to linking between the molecules of different types of polymers. The compatibilization process is required to reach effective stress transfer between the phases.

In our work, polymaleic-polyanhydride derivates have been synthesized and applied in ABS and HDPE blends. Firstly, intermediates were synthesized in organic solvent at 100-200°C. The esterification reaction of α-olefin-succinic-anhydride intermediates have been in solvent under nitrogen atmosphere by the use of catalyst, too. At the end of the reaction procedure the products were purified by evaporation of the volatile components and filtration. Glass fibre reinforced and unreinforced ABS wastes have been been also blended with HDPE. Specimens have been tested by tensile, flexural, Charpy testes and FTIR, SEM and SEC methods. By this way the recycling of ABS and HDPE can be done with improving mechanical properties of reshaped specimens. Proper selection in the composition of compatibilizing additives has been appointed to influence the poor mechanical properties of the blends in an advantageous way, e.g. yield strength could be improved by 30%. The styrene content of the additives seemed to have significant effect on the mechanical properties of the composites. Results demonstrate that the glass fibre reinforcements have been able to linking between the two immiscible phases and advanced mechanical properties could be measured. Furthermore the glass fibre could be taken stronger interfacial linking in the presence of experimental polymaleic-polyanhydride derivates. The positions of absorption peaks for >C=O bonds were shifted and the ratios of those with different chemical environment also could be changed. The reason for the abovementioned phenomena could be the precipitation from the reaction product, which was a styrene-maleic-anhydride copolymer according to FTIR spectrum analysis.
EVALUATION OF IFSS IN SHORT-FLAX-FIBER/PP COMPOSITES

J. Modniks, E. Poriķe, and J. Andersons

Institute of Polymer Mechanics, University of Latvia, Aizkraukles iela 23, LV-1006, Rīga, Latvia

An important factor influencing mechanical characteristics of composite materials is the adhesion of constituents which can be characterized by the interfacial shear strength (IFSS). Most of the experimental methods usually involve single-fiber composites for evaluation of IFSS. However, such tests may not reflect the actual stress state fibers are subjected to in a composite material. By contrast, the method proposed by Bowyer and Bader is based on the analysis of stress-strain curve of a short-fiber reinforced composite in tension.

A modified Bowyer and Bader method is applied to experimental tension curves of short-flax-fiber reinforced polypropylene to evaluate the IFSS and fiber orientation factor. The IFSS was found to depend on the volume fraction of fibers and the treatment to improve adhesion. An analysis of IFSS is performed to determine its relation to fiber volume fraction via residual stresses, assuming friction-dominated interfacial stress transfer.
ENHANCING THE THERMOMECHANICAL PROPERTIES OF AN EPOXY/CARBON FIBER NANOCOMPOSITES USING BY NANOREINFORCEMENTS

E. S. Molchanov¹, V. E. Yudin², and K. A. Kydralieva¹

¹Moscow Aviation Institute (State Technical University), Volokolamskoeshosse, 4, 125993 Moscow, Russia; e-mail: molchan_n.f@mail.ru
²Institute of Macromolecular Compounds, RAS, Bolshoy pr. 3, 199004 Saint-Petersburg, Russia

Polymeric materials reinforced with carbon fibers, or carbon composites represent a new generation of structural materials for orthopedic products that enable fundamentally change the technique for conservative treatment and rehabilitation of trauma and orthopedic patients in the postoperative period. Carbon fibers have high strength and stiffness, low weight, immunity to corrosive media which allows carbon-based composite materials adapt well to the contours of limbs in the manufacture of orthoses. Adhesion strength of polymeric binding agents with carbon fibers depends on many factors, as those are nature and structure of polymer, its adhesive potential towards fibers, application method, processing of fibers surface and others. Change of the nature and structure binding agent, including various nanoamendments, have various effects on mechanical properties of carbon plastic, as follows: modulus of elasticity, ultimate strength, density, loss modulus and storage modulus at heating.

This study is aimed to improve thermo-mechanical properties of carbon composite materials fabricated with nanomodificated epoxy resin. Solid epoxy olygomer Epicote-1004 modificat by montmorillonite, halloysite and carbon nanotubes, accordingly and commercially available carbon fiber PORCHER-43200 were chosen as the precursors for the epoxy/carbon fibers nanocomposites. Fabrication method of nanocomposites involves fabrication of carbon fiber prepreg using electrostatic spraying and then plastics formulation by hot pressing.

To compare the results of the study of thermo-mechanical properties of carbon fiber derived from these prepregs the model commercial prepregs Sigranex® PREPREG CE8201-200-45S and, consequently, carbon composites fabricated were tested. Dynamic mechanical analysis showed there was an obvious increase in storage modulus and glass transition temperature for the hybrid nanocomposites compared to that of the neat epoxy resin.
CORROSION OF STEEL IN HIGH-STRENGTH CONCRETE

R. Moldovan, C. Magureanu, and C. Negrutiu

Technical University of Cluj-Napoca, Faculty of Civil Engineering, Romania

The use of high quality construction materials is nowadays a necessity for an efficient and durable construction strategy. High strength concrete has proved very good physical-mechanical properties, but the durability of high strength needs further research. This paper is focused on the corrosion of steel embedded in high strength concrete beams with different concrete covers 20 and 25 mm, subjected to accelerated corrosion with and without cracks under service limit state. The concrete class studied is C80/95. The beams cross section is $b \times h$: 120x240 mm, with a length of 1100 mm. The longitudinal reinforcement used is Bst500S ($f_{yk}=500$ N/mm$^2$), and the reinforcement used for the stirrups is PC52 ($f_{yk}=355$ N/mm$^2$).

The corrosion set-up is presented in Fig.1. The electrolyte in the test is a 3% NaCl solution and the electrodes are the cathode (the embedded reinforcement) and the anode (the stainless steel plate, which covers symmetrically 3 faces of the beam). An external voltage is applied to the anode. The beams were subjected for 20 days to accelerated corrosion.

The study is conducted in 3 directions:

a) Beams with no exposure to accelerated corrosion and with no cracks under service limit state (SLS);

b) Beams loaded to a service limit state, cracked and then exposed to accelerated corrosion;

c) Beams with no cracks exposed to accelerated corrosion.

After exposure in conditions of accelerated corrosion, all beams were tested until failure. The behaviour of these elements to a service limit state was analyzed (deformations and crack opening).

Fig. 1. Electrolytic cell- photo.

REFERENCES


INFLUENCE OF TIME ON THE SERVICEABILITY LIMIT STATE FOR HSC BEAMS SUBJECTED TO BENDING

A. Muntean, C. Măgureanu, and G. Bărbos

Dept. of Structures, Faculty of Civil Engineering, Technical University of Cluj-Napoca, Romania

This paper presents the influence of service life long-term loadings on the behaviour of reinforced high strength concrete beams subjected to bending in the serviceability limit state (SLS). The behaviour under short-term bending loadings is analyzed regarding cracking pattern and state of deformations for the elements subjected to 5 years of long-term service life loadings.

All the tested elements are made of reinforced concrete of C60/75 high strength concrete class, with and without steel fibre addition. The reinforcement fibre volume ratio is \( V = 2 \% \). All beams were reinforced with PC52 steel type, \( f_{yk} = 345 \text{ N/mm}^2 \), with the longitudinal reinforcement ratio of \( \rho_l = 2.113 \% \).

To establish the long-term loading step, similar elements were tested up to failure at the age of \( t_0 = 160 \) days. Afterwards the beams were loaded at a value of long-term bending moment equal to 40\% of the ultimate moment \( M_u \). For 5 years the beams were maintained under these loads in an environmental chamber with conditions of constant temperature and relative humidity \( (T = 20^\circ\text{C} \pm 2^\circ\text{C}, \text{RH} = 60\% \pm 5\%) \), afterwards unloaded and tested to short-term loadings up to failure. Fig. 1 presents the short-term testing of the beams.

![Fig. 1. Short-term testing.](image)

Cracking patterns and state of deformation were analyzed first of all for the elements subjected to short-term loadings before long-term loading was applied, at the age of \( t_0 = 160 \) days, and secondly for the beams unloaded at the age of 5 years. The influence of steel fibre addition on the beams behaviour was also analyzed at the serviceability limit state, before and after long-term loading was applied.
CONTACT MECHANICS AND TRIBOLOGY OF POLYMER COMPOSITES

N. K. Myshkin

Metal-Polymer Research Institute of Belarus National Academy of Sciences, Gomel, Belarus

The technological development is connected with a widening application of polymers in industry. Polymer materials afford to lower the mass of parts along with increasing resistance to hostile environment. The main concept of polymer mechanics related to tribology consists of three basic elements involved in friction: deformation resulting in the real area of contact of rough surfaces, contact adhesion; shear and rupture of materials in the contact at sliding [1, 2].

The main feature of the polymer structure is that their macromolecules consist of the rigid segments which can rotate thus providing the flexibility of the molecular chains. Another feature of polymers is that strong chemical forces link the atoms in a polymer chain whereas the intermolecular forces which are significantly weaker link the chains. Formation of the real area of contact can be considered when taking account of polymer viscoelasticity and the effects of temperature and load in the contact.

The use of different fillers gives an opportunity of improving the tribological behavior of polymers. Solid lubricants such as polytetrafluoroethylene (PTFE), graphite, molybdenum disulphide added to polymers affect significantly the formation of transfer films on the counterface and decrease the friction coefficient [3].

In recent years, polymer nanocomposites have become more and more common [4]. The carbon nanomaterials, clays, and nanoparticles of metals are mainly used as nanofillers for plastics.

Polymer-based materials, coatings and films have found wide applications in all the areas of technology. Their operational capability has been widened relating to temperature range, load-velocity parameters, and environment. They are successfully used for making components of various tribosystems such as gears, bearings, cams, and parts covered with polymer coatings [5, 6].

The thin polymer films e.g. self-assembled monolayers formed by the chemical and physical adsorption of polymer molecules are prospective boundary lubricants in the fast-growing area of the memory storage devices, microelectromechanical systems and other precision mechanisms [7].

Polymers are taking over the areas traditionally occupied by other classes of materials. For example, the fast progress in nanotechnologies made possible the production of new types of efficient fillers which can be introduced to polymer matrix and the composites have been used as very efficient antifriction and wear-resistant materials. The structural features of polymers and the possibility of changing their properties within a wide range provide a variety of the tribological applications of polymer materials.

REFERENCES

PHYSICAL AND MECHANICAL PROPERTIES OF COMPOSITES BASED ON A LINEAR LOW-DENSITY POLYETHYLENE (LLDPE) AND NATURAL FIBRE WASTE

O. Nestore, J. Kajaks, and S. Reihmane

Institute of Polymer Materials, Riga Technical University, Azenes 14/24, Riga, LV-1048, Latvia

Natural vegetable fibers and their textile waste are perspective reinforcements for polymer modification, because they are ecologically perspective, nature friendly materials and their utilization in innovative polymer composites is defined by their low cost and density, as well as practically unlimited resources in nature with very fast ability to reproduction. These composite have good technological properties and for their processing are possible to use traditional polymer processing methods.

In present paper three kinds of natural fiber waste were used: cotton, flax and hemp. Prior to mixing all fillers were dried for 24h at 105\(^{\circ}\)C. As polymer matrix linear low density polyethylene (LLDPE) grade LL 6201 (MFI=50g/10 min., melting temperature T\(_{m}\)=123\(^{\circ}\)C) was utilized. The composite (a filler content from 10 up to 40 wt.\%) samples were manufactured by mixing the fibers waste with polymer matrix on two-rolls mills (T=150\(^{\circ}\)C, t=10 min.), then cooled, granulated (average size of unregulated geometry of granules were 2-4 mm) and pressed (T=150\(^{\circ}\)C, t= 5 min., P=10 MPa) in 1 mm thick sheets (tensile strength measurements) and by compression moulding (T=180\(^{\circ}\)C, t= 5 min) for impact strength tests.

The technological properties (fluidity) were estimated with melt flow index (MFI) measurements (diameter of capillary 2.06 mm, L=8 mm, T=190\(^{\circ}\)C, P= 2.16 kg). As was expected practically for all composites, the fluidity decreased with an increase of fiber content. MFI values drop down to 0.5-0.9 g/10 min for system with 30 wt.% fibers. Necessary to note that composites containing 40 wt. % filler do not flow at these conditions and MFI was not able to evaluate.

The physical-mechanical investigations showed that the tensile strength increase (from 10 up to 33 MPa) for all composites containing 30 wt. % fibers waste. But for systems with 40 wt. % fibers observe small drop of values of tensile strength (to 22 – 25 MPa). The yield elongation at break fastly decrease at the filler content in composites 10-20 wt. % and then change a little for systems with 30 and 40 wt.% fibers. Impact strength as was expected decrease considerably (from 43 to 11 kJ/m\(^2\)) with increase of all kinds of fillers content in composites. On the contrary, bending strength of specimens increase about 50 %, but flexural modulus of composites increase considerably (6-7 times) with the filler content up to 40 wt. %. Necessary to note, that the observed tendency of hemp fibers influences greater on linear low density polyethylene mechanical properties. For all investigated natural fibers waste containing composites optimal contents of fibers were 30 wt. % what is a little unexpected. For another polyolefines for example polypropylene and low density polyethylene usually observe higher optimal natural fibre fillers content (about 40-50 wt. %).

The presented investigations showed utilization possibilities of cotton, hemp and flax fibre textile waste as perspective reinforcements for linear low density polyethylene. The best results are gained if flax and hemp fibre are used for this purpose. Obtained thermoplastic composite materials can be processed by traditional polymer processing methods and products from these materials have well enough mechanical properties.
Mechanics of Composite Materials - 2012

FRICIONLESS INDENTATION OF A FUNCTIONALLY GRADED VITREOUS ENAMELED STEEL PLATE BY A RIGID SPHERICAL INDENTER

A. Nikbakht, M. Sadighi, and A. Fallahi Arezoodar

Department of Mechanical Engineering, Amirkabir University of Technology, Tehran, Iran

Graded materials, also known as functionally graded materials (FGMs) are multiphase composites with continuously varying volume fractions and, as a result, thermo-mechanical properties. FGMs exploit the heat, oxidation and corrosion resistance typical of ceramics, and the strength, ductility and toughness typical of metals.

Vitreous enamels are inorganic materials that are used as coatings for metallic components. These materials are based on a special ceramic-vitreous matrix in which specific additives are randomly dispersed.

Functionally graded vitreous enameled steel is a special class of this kind of metal-ceramic composite components, obtained by a two stage coating process: the deposition of the raw enamel material over the metal surface and the firing at high temperature of the metal-enamel system. Enameling the steel plates creates a graded medium between steel and enamel, mainly consisted of steel and SiO₂. Different processing techniques and enamel composition can change the volume fraction of the constituting phases in the graded medium. Enameled steel components are appreciated for their aesthetic properties as well as for their chemical characteristics. From the functional point of view, vitreous enamel coatings have an excellent resistance to chemical corrosion processes, a good resistance to tribological phenomena such as abrasive wear and the capability to prevent instability due to impact loadings. Although enameling of steel is a common process in different industries for numerous applications, some of the mechanical behaviors of enameled steel plates are yet to be studied. One of these behaviors is the performance of enameled steel plates under contact loading. The results obtained from the analysis of such loading can then be applied to analyze the impact and problems regarding tribological phenomena.

In this research, the indentation of a functionally graded (FG) vitreous enameled steel plate with finite dimensions by a rigid spherical indenter is studied. The plate is simply supported and the contact of the plate and the indenter is assumed to be frictionless. Two steps are considered in analyzing of the problem. In the first step, a set of tests are carried out on the mentioned contact problem for specific plate and indenter dimensions and material distribution to find the force-displacement curve of the indenter. In addition, in the first step, a simulation of the contact problem for similar dimensions and material properties to those of the tested specimens is done by using ABAQUS finite element package. The experimental results are then used to find the optimal mesh. In the simulations, the plastic deformation of the constituting phases of the plate is taken into account by using a volume fraction based model proposed by Tamura et al. (TTO model). The validity and accuracy of the ABAQUS model is controlled by a second set of experiments. In order to do so, a second set of tests are conducted with different plate and indenter dimensions from those of the first one. The results of the second set of experiments are compared with the simulations done by the obtained ABAQUS model. The experimental and ABAQUS results are in good agreement. As the second step towards studying the problem, the ABAQUS model is used to investigate the effect of parameters such as plate dimensions and material properties distribution on the force-displacement curve of the indenter. The simulations show that between two plates with the same thickness, an FG enameled steel plate has a higher load carrying capacity compared to a homogeneous steel plate. In addition, increasing the metal volume fraction in the graded medium causes the plate to sustain higher loads.
The use of hi-tech thermoplastic matrices (like PEKK, PEEK or PPS) in carbon fiber-reinforced composites is growing mainly in the aircraft industry. Manufacturing process is done at higher temperatures, which lead to the residual stresses and dimensional changes of the manufactured part. Presented article deals with the prediction of springback angle of C/PPS laminate with textile reinforcement, which is necessary for making the manufacturing tool more precise.

Model is based on the representation of the woven geometry according to [3]. Comparison is made for plain and satin weave where threads are constant parameters and the thickness of the fabric is changing. A solution for the straight fibers according to [1] is presented in the article and compared with woven solution. Effective thermo-mechanical characteristics for the three types of lay-up are computed by classic lamination theory and equations for the through thickness characteristics [2]. Springback model covers thermal expansion of the material and chemical shrinkage during cure cycle.

A comparison of the springback angle computed by the woven model and straight fibers model with the measured data from the manufacturer (see Fig.1) and also comparison of thermo-elastic characteristics obtained by each model are presented at the end of the article.

Fig. 1. Comparison of the analytical results and measurement from the manufacturer.

REFERENCES

MARKOV MODEL OF FATIGUE OF A COMPOSITE MATERIAL WITH POISSON PROCESS OF DEFECT INITIATION

Yu. Paramonov¹, R. Chatys², J. Andersons², and M. Kleinhofs¹

¹Aviation Institute, Riga Technical University, Lomonosova 1, Riga LV 1019, Latvia
²Institute of Polymer Mechanics, University of Latvia, Aizkraukles 23, Riga LV 1006, Latvia

In the development of [1, 2], we have considered only one weak micro-volume (WMV) and only a pulsating cyclic loading. In the current version of the model we take into account the presence of several weak sites in which fatigue damage can accumulate and also the effect of stress ratio of loading. The random process of initiation of these weak sites (micro-volumes) is modeled as the Poisson process. Let \( T_1, T_2, T_3, \ldots \) be fatigue lives of several WMVs. We assume that the instants of origination of WMVs form a Poisson process with a rate \( \mu \) so the time intervals between the initiation of the weak sites, \( X_1, X_2, X_3, \ldots \) have an exponential distribution with an average \( 1/\mu \). Let \( T_1, T_2, T_3, \ldots \) be fatigue lives of the WMVs. Then the cumulative distribution function (cdf) of the random variable \( Y \) (the time to failure of the “weakest” WMV), \( Y = \min(T_1, T_2 + X_1, T_3 + X_1 + X_2, \ldots) \), or \( Y = \min(T_1, X_1 + Y) \), where \( F_Y(y) = F_{Y_1}(y) \), is determined as follows: 

\[
F_Y(y) = 1 - \left( 1 - F_{Y_1}(y) \right) \exp(-\mu \int_0^y F_Y(t) \, dt). 
\]

The function \( F_Y(t) \) can be determined using Markov model of fatigue [1]. If it is approximated by a lognormal distribution, then

\[
F_Y(y) = 1 - \Phi(-z) \exp(-\mu(y \Phi(z) - \exp(\mu + \theta_L^2/2) \Phi(z - \theta_L))), 
\]

where \( \theta_L, \theta_L \) are the parameters of the lognormal distribution (they are functions of cycle maximum, \( S_m \), and minimum, \( S_m \), stresses), 

\[
z = (\log(y) - \theta_L)/\theta_L. 
\]

It can be assumed also that the rate of Poisson process is a function of the load and size of the specimen, for example: 

\[
\mu = c L F(S_m), 
\]

where \( c \) is the factor of proportionality, \( L \) is the length of specimen, \( F(.) \) is the cdf of the static strength. In [1, 2] we have considered only a pulsating cyclic loading. Now the stress \( S_{mx2}(R_2) \) of load cycle with stress ratio \( R_2 = S_{mx2}/S_{mx2} \) is “translated” into fatigue-life-equivalent cycle with 

\[
S_{mx,eq,2} = S_m (R_2)((1 - R_2^m)/(1 - R_1^m))^{1/m}, 
\]

with stress ratio \( R_1 \) using a modified energy method (parameter \( m \) is less than 2!). Let us note that in the considered model \( F_Y(y) \) defines the whole probabilistic fatigue diagram with \( S_m > 0 \).

Numerical examples are provided.

REFERENCES

The guided wave technology (GWT) is one of the most effective means of structural damage detection in the thin-walled structural elements. Its application for structural health monitoring (SHM) of aircraft is very perspective. This technology is applicable as for Al alloy, as composite structure and has many important advantages in comparison with others methods. The main of them is the ability to detect very large surface of structure at distance about some meters and more. Therefore, the properties of GWT are intensively investigated in view of practical use in the systems of SHM. In presented paper as a first step the computational simulation was performed for classical 2-D model of composite layer with some local damage. It shows fundamental properties of guided wave guided wave interaction with damage. The result of interaction with damage in thin-walled composite plate is shown in Fig. 1. Initial impulse is generated by a piezoceramics transducer that is glued on a surface of the plate in its center \((x = 0.25 \text{ m})\). In point \(x = 0.1 \text{ m}\) there is a small damage. It is possible compare \(S_0\) mode of impulse transformation and its partial conversion to \(A_0\) mode (left part of signal) with symmetrical signal in undamaged part of a plate (right part of signal). Both this effect can be effectively used in the system of SHM of thin-walled composite components of aircraft.

Some regularities of ultrasonic guided wave propagation in composite sheet with different kinds of damage were investigated by the simulation and also in special test. The problems of the use of GWT in SHM of aircraft for damage detection in composite components are discussed.

**Acknowledgement.** The research leading to these results has received funding from the European Community's Seventh Framework Program [FP7/2007-2013] under grant agreement n°212912. The authors are grateful to European Commission for financial support and all partners for scientific and technological collaboration.
The analysis of the features of direct impact of thin-walled composite component of aircraft was performed. Several types of impactors were considered in the respect of actual causes of impact damaging in the aircraft operation. More realistic results can be obtained by computational simulation of dynamic process of impact (Fig. 1). The effect of materials of contact pair, geometrical form of impactor, its mass and initial velocity as well as also structure of the thin-walled composite plate, material performance, boundary conditions and others parameter was investigated. Mainly the GFRP and CFRP laminates were selected in form either thin separate plate or sandwich structure. The velocity of impact was limited by 40 m/s. It can say the low-velocity impact was simulated. Typical result of simulation is shown in the Fig. 2. At the first stage of impact (before destruction of some component of composite) material was assumed as linearly elastic, homogeny and anisotropic.

Several conditions of destruction start were used for different kind of partial damage of composite (delaminating, the rupture of fiber, cracking of a matrix). The features of impact in the respect of mass-velocity effect were investigated.

Acknowledgement. The research leading to these results has received funding from the European Community's Seventh Framework Program [FP7/2007-2013] under grant agreement n°212912. The authors are grateful to European Commission for financial support and all partners for scientific and technological collaboration.
One of distinctive features of carbon-carbon composites is their low crack resistance due to the brittleness of the carbon matrix. At the same time, low-velocity impact loadings are widely met in actual practice. Therefore, a successful use of carbon-carbon composites requires investigations into their behavior under the action of this type of loading. The prime objectives of the present work were (a) to establish a relationship between the dimensions of the zone of possible delaminations and the stresses caused by the impact energy and (b) to elaborate an approach to evaluating the damageability of the composite materials upon the action low-velocity impacts which would allow one to obtain steady and repeatable results at a certain level of impact loading. To determine the dimensions of the zone of possible delaminations and the magnitude of stresses as functions of impact energy, a FE analysis was carried out. The distributions of contact stresses were assumed according to the Herz theory.

In the case of spherical striker, the contact pressure $p(x,y)$ is distributed ellipsoidally in a circular zone of radius $a$, which depends on the total contact force $P$ and the striker radius $R$. At the first stage, a relationship between the impact energy and the resultant of contact stresses (the contact force) was established. The calculation was performed by the method of successive approximations, with a gradual increase in the contact force. At the second stage, the dimensions of the zone of possible delaminations and the stress state caused by the contact force $P_k$ corresponding to a prescribed impact energy were determined. Assuming that the material loses its load-carrying ability in the zone where the equivalent Mises-Hill stresses exceed the ultimate strength $\sigma_{eky} > \sigma_p$, during the impact, at the third stage, a model of the damaged object was formed by employing the approach described in [1]. By using the FEM, the deflection $w_p$ was found at the point where the load was applied to the undamaged and impacted object loaded according to the three-point scheme. Then, the shear stiffness of the undamaged and impacted objects were calculated [2]. As the object of investigation, a square in plane carbon-carbon composite specimen with known mechanical characteristics was taken. The specimen was subjected to a low-velocity compressive or bending load. For various side-thickness ratios of the specimen, relationships for decreasing shear stiffness of the material as a function of a low-velocity compressive or bending impact were obtained.

REFERENCES

STRESS STATE AND STRENGTH OF PIEZOCERAMICS UNDER A STATIC LOAD

V. Pavelko, I. Pavelko, and S. Kuznetsov
Aviation Institute, Riga Technical University, LV-1019, Riga, Latvia

Structural health monitoring (SHM) of aircraft can be successful, if minimally two requirements are obeyed: (1) SHM system is able reliably detect all kinds of structural damages, and (2) Own reliability of SHM system is high. In ultrasonic SHM system the least defended element is a piezoceramics transducer integrated in structure. Conditions of aircraft operation are very complex: mechanical loading and vibration, environmental degradation, wide range of temperature and others. First of all the transducer is attached to the structural element. It means that it is loaded by alternative operational load. It can induce static or fatigue destruction of transducer. For example, Figure 1 shows a piezoceramics 0.5×10×50 mm transducer installed to an Al panel after about 60,000 cycles of loading with the alternative stress 150/50 MPa. The transducer was glued on a skin of panel in direction of load action. This level of stress is typical for Al alloy structure of aircraft. At least nine fatigue cracks on a surface of the transducer were detected by penetration. This effect associated with low tensile strength of piezoceramics that equal to 40–80 MPa. It is much less than compressive strength (about 600 MPa). The crack-resistance of piezoceramics is also low (the toughness about 1–3 MPa·m^{0.5}). There are some structural possibilities to protect piezoceramics from effect of mechanical loading. Pre-stressed transducer is good solution as from overloading as from corrosion. However, constraining decreases sensitivity of damage detection.

The influence of transducer parameters and its coupling with structural element to stress and strength is investigated in present paper. The theoretical model of strength for piezoceramics stripe glued to structural element was developed.

The concept of ‘weak chin’ and the results of stress state analysis of three-layers structure with the cracks in one of layers was used. The general tendencies of effect of this structure parameters were defined. The effect of mechanical loading of piezoceramics transducer to its stress state and destruction can be decreased by rational selection of its geometrical parameters and thickness of coupling layer (Fig. 2).

Acknowledgement. The research leading to these results has received funding from the European Community's Seventh Framework Program [FP7/2007-2013] under grant agreement nº212912. The authors are grateful to European Commission for financial support and all partners for scientific and technological collaboration.
FRACTURE OF FUNCTIONALLY GRADED/ HOMOGENEOUS BIMATERIALS WITH AN INTERFACE CRACK AND SYSTEMS OF CRACKS UNDER THERMAL AND MECHANICAL LOADING

V. Petrova\textsuperscript{1} and S. Schmauder\textsuperscript{2}

\textsuperscript{1}Faculty of Mathematics, Voronezh State University, Voronezh 394006, Russia
\textsuperscript{2}IMWF, University of Stuttgart, Pfaffenwaldring 32, D-70569 Stuttgart, Germany

Advanced composites, such as functionally graded materials (FGMs), have attracted growing interest because of their wide application in numerous branches of modern technology. Great progress was achieved in computational modelling of FGMs and cracks in FGMs. But the investigations devoted to the crack interactions in FGMs are restricted only to special cases of crack locations while the interaction of arbitrary located cracks with an interface was not well examined.

This work is devoted to the problem of modeling of the failure processes in the vicinity of an interface in functionally graded/homogeneous bimaterials with internal defects under combination of thermal and different mechanical loadings, i.e. thermal flux, Mode II shear loading and tensile loading. This combination of loadings causes mixed-mode stress-strain state at the vicinity of the interface crack and new effects can be observed connected with possible closure of the interface crack.

A previously obtained solution (Petrova, Schmauder, 2010, 2011) for the case of thermal loading on the same geometry is used as a part of the present solution. The solution is based on the integral equation method and it is assumed that thermal properties of the functionally graded material (FGM) possess an exponential form. An asymptotic analytical solution is derived for a special case where an interface crack is larger than internal cracks in the FGM. The stress intensity factors are presented as asymptotic analytical functions of geometry of the problem and material properties. Analyses of the effects of the location and orientation of the cracks and the material non-homogeneity parameters on the stress intensity factors in FGM/homogeneous bimaterials is performed in the presence of thermal and mechanical loading. Different combinations of the non-homogeneity parameters which control the variation of thermo-elastic properties in the FGM are considered. Examples of actual material combinations are discussed.

Acknowledgement. V. Petrova acknowledges the support of the German Research Foundation under grant Schm 746/113-1.
Conductive polymeric composites based on graphite or carbon derivates can be variously applied as electronic devices [1], antistatic coatings [2], biosensors [3], temperature sensors [4], electrodes for the metals detection [5] etc. The commercial expanded graphite (EG), used in this work, is a structural modification of graphite obtained from intercalated graphite via thermal reduction; the result is a worm-like structure, in which reduced attraction forces between the layers and high porosity exchange surface fit perfectly the requirements for a good dispersion in the matrix. The aim of this work is to describe the influence of EG on PP matrices in composites prepared with twin screw extruder treatment followed by compression moulding process. Melt mixing method is fast and does not require any solvent, this is a relevant advantage for industries. Morphological studies have been performed to correlate the microstructure of the composite to the mechanical and rheological behaviour. Furthermore, thermal and electrical conductivities have been measured due to their importance in several modern applications and to evaluate the effect of graphite reticulation above the percolation concentration on the properties of polypropylene.

REFERENCES

ANALYSIS OF THE STRESS-STRAIN STATE OF LAMINATED CYLINDRICAL SHELLS UNDER A LOCAL LOADING BY A SEMI-ANALYTIC FINITE ELEMENT METHOD

V. G. Piskunov, A. V. Marchuk, and S. V. Gnedash

National Transport University, Kiev, Ukraine

A variant of semi analytic finite-element method is worked out for analysis of cylindrical shells under axisymmetric stress-strain state. The required functions for the construction are approximated with linear polynomials and their thickness is to be found on the basis of solving the corresponding system of differential equations. Using the developed methods, the analysis of the stress-strain state of cylindrical shells under the influence of local loads was carried out. The necessity of taking into account the spatial nature of deformation in solving problems of similar category was showed.
The work presents a proposal of modelling and investigation of advanced piezo composite MFC actuator application in one-dimensional flexural vibrating system. It is concerned with the previous works where systems with classical PZT piezoelectric transducers were analyzed [1,2]. In this case the Macro Fiber Composite (MFC) piezoelectric actuator is being taken into consideration. MFC transducers are consisting of rectangular piezo ceramic rods sandwiched between layers of adhesive, electrodes and polyimide film. The invention of MFC transducers was a very important step in piezoelectric transducers development process that was done in 1996 by NASA. Main benefits of the MFC given by the manufacturer are: increased strain actuator efficiency, damage tolerance, environmentally sealed packages, available as elongators and contractors [3, 4].

The presented method of analysis of the considered system is based on the discrete-continuous mathematical model of the system and an approximate Galerkin method [1,2]. The considered system is a cantilever beam with a piezoelectric actuator bonded to the beam’s surface. The actuator is supplied by an electric harmonic voltage. Characteristic $Y_V$ that describes relation between the beam’s deflection and applied voltage was calculated in accordance with definition:

$$y(x,t) = Y_V \cdot U(t),$$

where $y(x,t)$ denotes the beam’s deflection and $U(t)$ is the externally applied electric voltage.

The next step of the work was an analysis of influence of the piezoelectric Macro Fiber Composite’s properties on the obtained characteristic of the system. Obtained results are presented as three dimensional charts.

REFERENCES

SOME FUNCTIONAL PROPERTIES OF A COMPOSITE MATERIAL BASED ON SCRAP TIRES

R. Plesuma, A. Megne, I. Mateusa-Krukle, and L. Malers

Department of Polymer Materials Technology, Riga Technical University, Latvia

The utilization of scrap tires still obtains a remarkable importance from the aspect of unloading the environment from non-degradable waste [1]. One of the most perspective ways for scrap tires reuse is a production of composite materials [2]. The present research must be considered as a continuation of previous investigations [3, 4] and it is devoted to clarification of some functional properties of composite material which are considered important for the view of practical applications of particular material.

In this work vital properties of composite material were investigated, for instance:

- compressive stress at different extent of deformation of sample (till 67% of initial thickness) (EN 826);
- water absorption (EN 12087);
- water permeability (introduced method);
- resistance to UV radiation (modified method based on EN 14836)

Experiments were realized on purposefully selected samples of composite material in correlation with potential changes of such characteristics like apparent density AD (kg/cm$^3$) (EN 1602) and Shore C hardness (Shore scale, according to ISO 7619; ISO 868) of material.

In addition to this correlation between content and activity of polymer binder used in the production of composite material samples and some technological parameters with mentioned above properties and characteristics of the material were clarified.

The results showed that investigated samples of composite material demonstrate significant resistance against mechanical and UV radiation influence in close correlation with composition of material, activity of binder, definite technological parameters and conditions supported during production of material samples.

It was estimated that selected properties and characteristics of composite material are strongly dependent not only from composition and technological parameters used in the production of composite material, but also from rubber crumb used (fractionated particles by sieve size).

Obtained results show possibility to attain desirable changes in the composite material properties by changing both composition and technological parameters of examined material.

REFERENCES

WAVE TRANSMISSION IN HOLLOW ANISOTROPIC SPHERICAL SHELL
SUBMERGED IN AN INCOMPRESSIBLE LIQUID

V. Polyakov

Institute of Polymer Mechanics, University of Latvia, 23 Aizkraukles, LV-1006, Riga, Latvia

The now perspective investigations have a concern in the problem-solving technique for composite structure behavior in fluid and gaseous media. The model solution to wave problem at the particular requirements of interfacial contact becomes the issue under discussion. The estimation procedures of physical properties, in particular, anisotropy of material on wave intensity are now getting under way. Closed boundary analysis is appreciably related to transient oscillations under wave disturbance arising from a small -amplitude acoustic pressure applied to the inner surface of a hollow anisotropic sphere.

With reference to layered structure of a thick sphere made of thin spherical diaphragms, the wall of a solid sphere can be classified in this case as the stratified material exhibiting transversal isotropy. The theoretical approach using an operational solution technique of wave equations and applying the functions of complex variable enables us to study a correlation between the intensity of acoustic radiation and structural parameters, emitting surface and physical properties of fluid. Herewith, the boundary value problem on eigenfrequency obtaining is performed with the help of the theory of residues. The method suggested here can be applied to predict the dynamics of a spherical shell with an arbitrary thickness because no assumption about the deformations of the shell has been employed.

Free vibrations of an anisotropic spherical shell, which is submerged in the incompressible liquid medium, are analyzed. Numerical computation ascertained that the eigenfrequency spectrum of the sphere in the light liquid is identically the same as the corresponding spectrum in vacuum, i.e., in the absence of the liquid. Liquid mass density has essentially effect on the frequencies of submerged anisotropic spherical shell (Fig. 1).

\[ \lambda_k = \frac{\omega_k R_0}{c} \]

Fig. 1. Relative natural frequencies \( \lambda_k = \frac{\omega_k R_0}{c} \) of a hollow anisotropic sphere submerged in heavy, \( H (\gamma = 1) \) and light, \( L (\gamma = 400) \), liquid.

\[ \beta = \frac{E_g}{E_r}, \quad \gamma = \frac{\rho_{sphere}}{\rho_{fluid}}, \quad \text{and} \]

\[ \frac{R_1}{R_0} = 0.50, \quad \nu_{ll} = \nu_{rl} = 1/3. \]
HYPERTROPHY OF SKELETAL MUSCLES AND AN OVERWEIGHT DISTINCTION METHOD IN ATHLETES

I. Pontaga

Dept. of Anatomy, Physiology, Biochemistry and Hygiene, Latvian Academy of Sports Education, LV-1006, Riga, Latvia

Body mass index (BMI) is a useful screening tool for overweight and obesity diagnostics in people. Human body parts proportions and body mass composition are not taken into account if anybody determines BMI from tables of norms. There are 12 - 15 % of fat tissues in young male’s body in norm [1]. The BMI depends not only on the fat content in the body, but also on the muscles and bones mass, as well as, on the water content in the body. High value of the BMI can be estimated as overweight in athletes with great skeletal muscles mass. This means that training in many sports specializations (weight lifters, body builders, rowers etc) causes increase of the BMI [2]. The aim of the present investigation is to prove that an increased BMI in adolescent and young handball players does not always give evidence about overweight or obesity, but may appear due to skeletal muscles hypertrophy.

Eleven male handball players from the team of Latvian Academy of Sports Education (LASE)(the mean age 20.0 ± 1.0 years, height - 186.7 ± 8.1 cm, weight - 84.7 ± 11.1 kg) and nine adolescent male handball players from Murjani Sports Gymnasia (the mean age 17.6 ± 1.0 years, height - 182.4 ± 7.1 cm, weight - 86.3 ± 8.2 kg) participated voluntarily in the investigation. Athletes from both teams trained five times per week and had competitions every weekend at least five years. The measurements were performed in the Latvian Sports Medicine Agency. The BMI was calculated for every athlete using the equation (1) [1]:

\[ \text{BMI} = \frac{m}{h^2} \]

where: \( m \) is a body mass in kg; \( h \) is a height of athlete in m.

The body mass composition was measured by the bioelectrical impedance analysis method using the Body Composition Analyzer „X – Scan Plus” (Jawon Medical, Korea). Every athlete had to stay straight on the platform of the apparatus during the measurements. All athletes were weighted by the scales included in the Body Composition Analyzer. The height was measured by special ultrasound device (UHM – 101) build in the Body Composition Analyzer. Body mass composition is estimated by measurement of the electrical resistance to a small, alternating current flowing between four electrodes: two electrodes are positioned below the feet of every athlete and two electrodes are hold in the hands. The obtained data were automatically processed taking into account the height, body mass, gender, and age and body tissues electrical resistance of every examined athlete.

The BMI mean value is close to the upper border of norm in handball players (24.2 ± 1.7 kg/m²) from the team of LASE. The overweight can be determined due to high BMI (25.1 ± 2.9 kg/m²) in adolescent handball players from Murjani Sports Gymnasia, but this is due to high lean body mass. The body fat content in handball players (13.6 ± 2.8 %) is in norm.

REFERENCES

SCALE EFFECT OF THE TENSILE STRENGTH OF ELEMENTARY HEMP FIBERS

E. Poriķe

Institute of Polymer Mechanics, University of Latvia, Aizkraukles iela 23, LV-1006, Rīga, Latvia

Bast fibers of such plants as hemp, flax, jute etc. are attractive as a reinforcement of polymer-matrix composites due to their high specific stiffness and strength in the axial direction. The elementary bast fibers exhibit pronounced scatter of strength. Fiber fracture is shown to originate from mechanical defects of the bast cell wall, the most prominent of them being kink bands. Application of hemp fibers as reinforcement of composite materials necessitates characterization of fiber strength scatter and the effect of fiber length on its strength. Analytical distribution function of bast fiber strength has been derived, allowing for the effect of mechanical damage in the form of kink bands. The hemp fiber characteristics measured have been used to evaluate the kink band density and strength distributions. The theoretical distribution is verified against experimental tensile strength data of elementary hemp fibers at two gauge lengths and found to provide acceptable accuracy in predicting the scale effect of strength.
Mechanics of Composite Materials - 2012

GRIPPING DEVICE FOR TRANSMISSION OF TENSILE LOAD TO FRP STRIP

G. Portnov, V. Kulakov, and A. Arnautov

Institute of Polymer Mechanics, University of Latvia, LV-1006, Riga, Latvia

Strengthening, upgrading, and retrofitting of the existing structures are among the challenges that modern structural engineering is facing today. One of the most promising answers to these needs is the use of strips made of fiber-reinforced plastics (FRPs), which are bonded to the tensile face of the structural member or used as the stay cables or guys. The advantages of FRPs offer great potential for efficient, applicable, and cost-effective strengthening.

The present research is devoted to the design and calculations of a gripping device for transmission a tensile load to a flexible FRP strip. Such devices are necessary for pre- and post-tensioning of the FRP strips and their testing in tension.

The transmission of an external tensile load to the composite strips is the key problem for their use and testing. Tensile load is transmitted to the stretched strip through the shear stresses induced on its surface by friction during the strip microslipping in the gripping device. In the case of an adhesive joint, the tensile load is transmitted to the stretched composite strip through the shear stresses induced in the adhesive layer. In both cases shear stresses at the load transmission area are distributed non-uniformly. There is a stress peak at the point of strip entry into the anchorage or gripping device. As was shown by the authors of this research, this peak produces also the normal stress concentration in the near-surface layers considerably exceeding the mean stress in the tensioned strip. Such situation causes the premature failure of the tensioned strip near the anchorage entry and does not allow us to achieve or determine its real maximum load-carrying capacity corresponding to attainment of tensile strength by uniformly distributed stress in the working area of the strip. Therefore, there is a need in a simple and effective gripping device, which has no shear stress peak at the entry point.

This objective is achieved by the gripping device proposed, which comprises of the two parts. The first part has a through slit adapted to accommodate the flexible FRP strip, wherein the through slit constitutes a wavy curve in its longitudinal section. A curvature of the wavy curve at an entry point into the through slit must be zero, and the local maximum values of the curvature in each subsequent wave should be greater than in the previous one; wherein the load is transmitted to the flexible FRP strip due to the friction forces arising from the flexible FRP strip tensioning into the through slit and microslipping over the curved surfaces of the slit. The second part of the device is adapted to fasten, in relation to the first part, an end of the flexible strip emerging from the exit point of the through slit. In such gripping device the stresses in the flexible strip are smoothly changing along the slit in the first part. The absence of stress peaks in the flexible strip allows increasing the transmitted tensile load.

In the present work, the profile of the slit is described by equation:

\[ y_m(x_m) = A \cdot x_m^b \cdot \exp\left(-k(1-x_m)\right) \sin(\omega(1-x_m)+\alpha), \]

where \( x_m = x/L, y_m = y/L, \) \( L \) is distance between entry and exit points of the slit, \( A, b, k, \omega, \alpha \) are dimensionless parameters.

Stress-state in the strip, located and tensioned into the slit, is calculated and analyzed using the equations for flexible elastic rods. Mechanical properties of the CFRP strip with thickness 0.5 mm were used for the numerical calculations. Such strip was also loaded and tested using the gripping device designed accordingly with the results obtained in the present investigation.
FIBER/MATRIX INTERFACE DEBOND GROWTH IN THE VICINITY OF THE SURFACE OF A UD COMPOSITE SUBJECT TO CYCLIC LOADING

A. Pupurs and J. Varna

Department of Engineering Sciences and Mathematics, Luleå University of Technology, SE 97187, Luleå, Sweden

Fiber/matrix interface debond growth is one of the main damage evolution mechanisms in unidirectional (UD) polymer composites subjected to cyclic fatigue loads. To evaluate the interface debond growth, strain energy release rate (G) calculations were performed.

A 3-D FEM model was developed for fiber/matrix interface debonds at different locations in the UD composite (see Fig.1.) including the composite surface region, where the stress state differs from the one in the bulk composite. For the bulk composite, where the stress state around the fiber break can be approximated as axisymmetric, analytical [1] and numerical [2] models were used to calculate G.

Simulations of interface debond growth in mechanical fatigue were performed and the modeling results were compared with experimental data available in the literature [3].

Fig. 1. Geometry fragment of the 3-D FEM model: ld is debond length; lc is distance from composite surface to center of the fiber; Ls is half length of the FEM model.

REFERENCES

NATURAL HEMP FIBRE AS ADDITIVES TO FORM POLYMER COMPOSITES

A. Putnina¹, S. Kukle¹, and J. Gravitis²

¹Riga Technical University, Institute of Textile Materials Technologies and Design, LV – 1048, Riga, Latvia
²Laboratory of Biomass Eco-Efficient Conversation, 27, Riga LV-1006, Latvia

Hemp bast fiber is Latvian renewable resource, which is rich in cellulose. High mechanical strength of crystalline cellulose pays the attention of scholars, which are searching for methods to extract the cellulose nanofibres from it. They could find wide application in various technological fields. Therefore is carried out intensive studies of pulp processing in the form of nanowhiskers, nanofibres, nanoparticles. Acquisition of nanofibres from cellulose bast fibers poses a problem because cellulose is insoluble/soluble difficult in practice-use solvents. Besides, cellulose macromolecules are integrated into microfibrils in the bast fibers, which are merged into macrofibers, fibers, fiber bundles, technical fibers and each of the entities in addition to crystalline cellulose contains amorphous areas/cover ligno-cellulosic, lignin, pectin, and/or in wax form that should be removed before electrospinning process using alkali treatment and steam explosion technique (STEX). Steam explosion is a promising technique to decompose natural fibre hierarchical structure down to microfibrilles. Also, lignines and pectines, sugars and other components can be removed by this method. During the STEX process, fibres are chemically modified and mechanically defibrillated. At the end of the steaming process, the instantaneous release of pressure stops the reaction and separates the fibres [1].

Disintegration of dew-retted hemp fibres of Latvian local genotype Purini grown in Agricultural Science Centre of Latgale by alkali treatment and steam explosion were investigated. Alkali treatment of fibres Purini under investigation with 4 wt. % NaOH during 1 h at a temperature 80°C is used. Treatment with alkali leads to the removal of cementing materials like lignins, hemicelluloses and pectins which will result in the increase of crystallinity percentage of the fibre [2]. Fourier Transform Infrared (FTIR) spectrograms of untreated and treated hemp fibres allow evaluate alkali and steam explosion treatment removal effectiveness of hemicelluloses and pectins. SEM micrographs of fibre surface show that after alkali treatment fibre surface is cleaner and fibre bundles are separated to a smaller bundles or elementary fibres, with a highly serrated surface. Steam explosion treatment and extraction of water-soluble and alkali-soluble components allows split hemp fiber structure of the constituent elements only in part to the size corresponding to the spinning suspension formation. Further studies designed to increase the processing rate of fiber preparation processes for STEX; as well as the application of a higher value of log Ro in STEX process to ensure fiber degradation efficiency; fiber agglomeration and the resulting micro-fiber preparation for electrospinning process.

REFERENCES

SYNTHESIS OF THE MAXWELL MODEL BASED ON NANOPARTICLES

M. A. Ramazanov$^1$ and M. S. Aslanov$^2$

$^1$Dept. of Physics, the Baku State University, AZ-1073/1, Baku, Azerbaijan  
$^2$Dept. of Automatics and Computer Technologies, AZ-1073, Baku, Azerbaijan

At present, the establishment of effective technologies for the development of oil reservoirs is highly appreciated. For one such technology is based on the use of nanoparticles [1-3]. Provided that the oil-containing systems are described by viscoelastic or viscoplastic models, the problem arises on describing the model media with interactions at the atomic or molecular level. Excluding the nanoparticles for describing these media, a model of a viscoelastic body, in particular, the model of Maxwell is introduced. To study the impact of nanoparticles it is appropriate to take into account the influence of parameters in the models of viscoelastic media, characterizing the properties of small nanoparticles.

In this paper, we consider the synthesis of the simple Maxwell model [2]. It consists of parallel connected $n$ simple models of Maxwell. In turn, the Maxwell's simple model consists of coherently interconnected elastic and viscous element.

Assuming that the inclusion of nanoparticles does not affect the form of determinant equations of the model, it is shown that the defining equation of the Maxwell model, taking into account the form of nanoparticles appears as the following:

$$
\sigma(t) = \sum_{i=1}^{N} \sigma_i(t) = \varepsilon(t) \sum_{i=1}^{N} E_i E_{N_i} - \int_0^t \varepsilon(\tau) \sum_{i=1}^{N} \left[ E_i e_{N_i} \right] \mu_i \exp \left[ -\mu_i E_i e_{N_i} \nu_{N_i}(t-\tau) \right] d\tau \equiv \\
= \varepsilon(t) E_{0N} - \int_0^t \varepsilon(t) \cdot \Gamma_N(t-\tau) d\tau,
$$

(1)

where "$i$" means that the value is related to the first Maxwell model $i$ and "$N$" with nanoparticles; $E_{0N}$ is the synthesized modulus of elasticity, $\Gamma_N(t-\tau)$ is the synthesized core strength with consideration of nanoparticles.

It is shown that if the elastic connection of nanoparticles meets the following inequality $\frac{E_{N_i}}{E_i} < 1$, then the addition of nanoparticles in the viscoelastic fluid leads to increased deformation. Otherwise, the addition of nanoparticles leads to a decrease in deformation. Hence, for the Maxwell model of the viscoelastic fluid by adding nanoparticles with certain properties the value of deformation, i.e. the properties of the model can be changed.

REFERENCES

THE EFFECT OF A UNIFORM MAGNETIC FIELD AND RADIATION MODIFICATION ON THE MECHANICAL PROPERTIES OF BLENDS OF A HIGH-DENSITY POLYETHYLENE WITH CHLORINATED POLYETHYLENE

I. Reinholds¹, V. Kalkis, and R. D. Maksimov²

¹Faculty of Chemistry, University of Latvia, Latvia
²Institute of Polymer Mechanics, University of Latvia, Latvia
e-mail: Valdis.Kalkis@lu.lv

The effect of a uniform magnetic field and ionizing radiation on the mechanical properties of polymer blends consisting of high-density polyethylene (HDPE) and chlorinated polyethylene (CPE) has been investigated. This study is a continuation of the investigation presented in [1], where only one HDPE/CPE composition (80/20 in w.%/w.%) was researched.

The purpose of the investigation was to create HDPE/CPE blend composites of significantly different compositions (with an excess of HDPE, intermediate ones, and with an excess of CPE) and to study the influence of magnetic field and radiation on the blends with different component ratio.

The investigation of magnetic field effect on the properties of polymer composite materials has importance from the engineering viewpoint, since there are structural elements in the fields of thermonuclear and engineering applications, that consist of polymer materials as wires, insulation materials and others, which are frequently subjected to mechanical loadings under the effect of magnetic field greater than 1 T [2, 3].

One part of the blends has been irradiated with 5 MeV accelerated electrons up to absorbed dose $D$ equal to 150 kGy. Unirradiated and the radiation cross-linked modified blends have been exposed to a constant magnetic field with induction $B$ equal to 1.0, 1.5 and 1.7 T.

It is found that the action of the magnetic field decreases the elastic modulus of unirradiated materials. For example, at a magnetic induction $B = 1.7$ T, the value of $E$ decreases almost 1.7 times for pure ABPE. Increment of the content of CPE in composites decrease the effect of magnetic field. The value of $E$ for HDPE/CPE composite with the ratio of components 20/80 decreases only 1.1 times at a magnetic induction $B = 1.7$ T.

It is also found that preliminary irradiation noticeably decreases the effect of magnetic field. The values of $E$ remained practically unchanged for radiation modified blends after the irradiation up to absorbed dose $D$ equal to 150 kGy applied to magnetic field with the induction $B$ in the range from 0 to 1.7 T in comparison to that of unirradiated specimens.

Data of the influence of the magnetic field, radiation cross-linking, and the ratio of the components on the creep are also obtained.

REFERENCES


HYGROTHERMAL EFFECT ON THE IMPACT RESPONSE OF CARBON COMPOSITES WITH EPOXY RESIN ENHANCED BY NANOCLAY S

P. N. B. Reis\textsuperscript{1*}, A. P. Silva\textsuperscript{1}, P. Santos\textsuperscript{1} and J. A. M. Ferreira\textsuperscript{2}

\textsuperscript{1}Depart. of Electromechanical Engineering, University of Beira Interior, Covilhã, Portugal.
\textsuperscript{2}CEMUC, Department of Mechanical Engineering, University of Coimbra, Pinhal de Marrocos, Coimbra, Portugal, e-mail: preis@ubi.pt

Impact damage is probably the primary cause of in-service delamination in composites and consequent reduction on the residual strength. The poor tolerance to accidental low velocity impacts of composite laminates is yet a limitation to their use in many applications for some industries. One way to improve the mechanical, impact and thermal properties of polymeric materials is the incorporation of filler materials. Nanoparticles have been widely studied and applied in numerous engineering areas due to its unique surface effect, increased chemical activity and particular physical properties. The aim of this work is study the hygrothermal effect on the impact response of carbon composites with epoxy resin filled by nanoclays, specially treated to improve the dispersion and interface adhesion. The results of the present paper are discussed in terms of load-time, load-displacement and energy-time diagrams. The fillers promoted a small increase of maximum impact load, a slight decrease of the displacement and higher values in terms of elastic recuperation. The exposure of the materials at 60 °C increases the absorbed energy; however, this tendency is more expressive when the water is combined with the temperature effect.
APPLICATION VALUE OF FRACTURE TOUGHNESS TO THE EVALUATION OF THE QUALITY OF A BUTT FUSION JOINT OF POLYETHYLENE PIPES REINFORCED WITH ALUMINA-BASED PARTICLES

A. K. Rodionov, F. I. Babenko, and Y. Y. Fedorov

Institute of Problems of Oil and Gas of the Siberian Branch of the Russian Academy of Science, Yakutsk, Russia

The results of samples of pipeline polythene ПЭ63, ПЭ80 and ПЭ100 and their welded joints (WJ) testing for short-term strength at a tension are analyzed. Experiments are carried out on the standard and model (with removed burr and a cut) samples in a temperature range 293-213K and speeds of tests 5-500 mm/min.

Values of parameters of limits of fluidity $\sigma_T$ materials of pipe are certain, constructed and approximated corresponding analytical (linear) dependences of parameters on speed of tests. Settlement-experimental parameters of conditional critical coefficient of stress intensity (CSI) and limits of crack resistance in the basic material of pipes and in a joint zone are certain. It is established, that dependence of conditional parameters of critical CSI from speed of tests passes through a maximum, and a limit of crack resistance in a joint zone is essential below 10-20 %, than in the basic material of pipes.

The qualitative model is proposed and interpretation of prominent features of a relief of surfaces of a break of model samples WJ with cuts is made. Within the limits of a developed settlement-experimental technique, the estimation of values of parameters of fluidity of materials (ПЭ63 and ПЭ80 is made, at $T=213K$ and speeds of test of 100 and 500 mm/min) in a joint zone. The estimation shows, that a limit of fluidity (conditional) in a joint zone is above, than in the basic material of a pipe.

It is proposed to add the list of test methods, obligatory at monitoring procedure of WJ quality, according to the joint venture 42-103-2003, by a test method of model samples on crack resistance. Thus the criterion of definition of WJ quality is proposes to choose a limit of crack resistance of a joint zone material, defined settlement-experimentally by testing for short-term strength at a tension of model WJ sample. Test specifications should provide a condition of “the limited fluidity” in top of a cut of the model sample ($\sigma_N \leq 0.8\sigma_m$ where $\sigma_N$ is a true pressure in the safe part of section of the sample), that is practically carried out at $T=213K$ and speeds of tests of 100 and 500 mm/min.
Increasing application of polymer matrix fibre composites in lightweight constructions has brought about considerable effort in modelling the material and structural behaviour. Besides laminate analysis and failure prediction major attention is turned towards simulation of the manufacturing process aiming at models and means for producing structures ‘right first time’. Several different aspects like fibre cutting, draping, filling pattern and online thickness measurement have to be observed in order to end up with a high-quality product. After demoulding plane structures often show a warpage and angles do not reach the designed values (spring-in). Svanberg [1] has listed a number of factors with different influence on the shape distortions. At the DLR considerable effort has been put into the development of methods for simulating the distortions in order to avoid them by counter measures. Wille et al. [2] pointed out that besides an empirical, trial and error based procedure there is a choice between simulation-based and semi-analytical approaches. This paper focuses on the latter ones as being fast and sufficiently accurate for the initial design. Spring-in is observed at curved structures. Radford and Diefendorf [3] have developed a simple formula where the amount of spring-in depends on the difference between in-plane and transverse properties. Spröwitz et al. [4] have shown that an equivalent coefficient of thermal expansion can be determined with L-shaped coupons. With the aid of this coefficient the spring-in of more complex structures can be calculated with sufficient accuracy. Experiments showed considerable warpage of plain structures especially for slender plates. A simple formula based on the classical lamination theory was developed by Kappel et al. [5]. Measurements with test specimens determine the unknown parameter. Comparisons with detailed FEM analyses as well as with experimental results will demonstrate the accuracy and the possible range of applicability of the proposed methods.

REFERENCES

VALIDATION OF A HEURISTIC FIBRE PLACEMENT ALGORITHM: 
STATISTICAL ANALYSIS OF REAL AND SIMULATED FIBRE ARRANGEMENTS

V. Romanov, S. V. Lomov, L. Gorbatikh, and I. Verpoest
Departement of Metallurgy and Materials Engineering, KULeuven, Kasteelpark Arenberg, 44 B-3001, Leuven, Belgium

Finite Element (FE) modeling of damage initiation and progression in unidirectional (UD) fibre-reinforced composites (FRCs) requires generation of Representative Volume Elements (RVEs) adequately representing the real random fibre placement. Simple random generation of fibre centers cannot create non-overlapping configuration for fibre volume fraction (VF) over 50...55%. Random Microstructure Generation (RMG) method [1] overcomes this difficulty by using a heuristic algorithm of movement/adding fibres in the RVE till the desired VF is reached. The algorithm allows creation RVEs with VF up to 75%, with computational expenses much lower than in more rigorous methods based on molecular dynamics analogues.

However, the method was not fully validated in [1]: it is not investigated (and this is the aim of this work) whether RMG algorithm creates fibre arrangements statistically equivalent with real UD FRC microstructures. The statistical equivalence is defined as (1) equivalence of distributions of the mutual fibre positions, expressed as, for example, distance/orientation distribution of the nearest neighbour, or number of fibres clustering within a given distance; (2) equivalence of statistical parameters of stress-strain field under typical RVE loading (tension, shear...), for example, distribution of von Mises stress in the matrix or of the maximal normal or tangent component of stress on fibre/matrix interface. The analysis is carried on using experimental fibre distribution in yarns of non-crimp 3D woven carbon/epoxy composite [2], with VF = 60...68%.

The results show good correlation between both the geometrical and mechanical statistical parameters of the real fibre placement and the simulated RVEs. The RMG method [1] is hence validated for definition of micromechanical FE models of UD FRC materials.

Fig. 1 Stages of the statistical validation: (a) RVE with VF=62% created by RMG algorithm, (b) Ripley’s K function for real and RMG fibre placement, (c) von Mises stress field of RVE under transverse tension.

Acknowledgement. The work has been funded by EC, “IMS&CPS” (FP7) project.

REFERENCES
ANALYSIS OF THE NONLINEAR BEHAVIOR OF BIO-BASED POLYMERS REINFORCED WITH FLAX FIBERS

L. Rozite and R. Joffe

Dept. of Engineering Sciences and Mathematics, Luleå University of Technology, S-97187, Luleå, Sweden

In last years competitive bio-based composite materials have been developed to reduce the dependence on non-renewable oil-based polymers and composites. This work is performed on composites with two bio-based matrix materials reinforced with flax fibers, Polylactic acid (PLA) and lignin. PLA is one of most commonly used bio-based thermoplastics, whereas lignin is relatively new material for composite applications.

The stiffness of bast fibers (e.g. flax, hemp) in longitudinal direction is comparable to that of glass fibers (for example flax fibers have stiffness 50-100 GPa vs 72 GPa for E-glass fibers). The direct benefits of use of natural fibers in composites are light weight, reduced wear on the processing equipment and lower impact on the environment. However, their mechanical properties are subject to large variation and composites made of these fibers are sensitive to moisture and humidity.

Study [1] has shown that in natural fiber composites the mechanical properties of fibers and the matrix are inherently nonlinear and the composite exhibits complex time dependent stress-strain behavior with loading rate effects and hysteresis loops. The phenomena dominating mechanical behavior may also include evolving microdamage (cracks, debonds etc) resulting in elastic properties degradation and development of irreversible strains. Therefore, material models of these materials should account for viscoelasticity and viscoplasticity accompanied with microdamage.

In the present study, systematic investigation of mechanical behaviour of flax fiber reinforced Lignin and PLA composites in tension is done. The objective is to indentify material model for these composites and to analyze the significance of viscoelastic, viscoplastic and stiffness reduction effects on mechanical behaviour.

REFERENCES

ANALYSIS OF THE TIME-DEPENDENT BEHAVIOR OF BIO-BASED COMPOSITES MADE FROM HIGHLY NON-LINEAR CONSTITUENTS

L. Rozite¹, R. Joffe¹², J. Varna¹, and B. Nyström²

¹Dept. of Engineering Sciences and Mathematics, Luleå University of Technology, S-97187, Luleå, Sweden
²Dept. of Materials and Manufacturing, Swerea SICOMP, S-94126, Piteå, Sweden

Large number of studies has been made about renewable bio-based (e.g. flax, hemp reinforced composites) composites during the last years. It has been shown that mechanical properties of bio-based composites compares well with glass fiber composites, especially if the properties are normalized with density.

However, there are some drawbacks with respect to utilization of natural fiber properties to the extent that composites based on these reinforcements also can compete with synthetic materials, such as limited fiber length, sensitivity to the moisture, temperature etc. But probably one of the major drawbacks of natural fibers is variability of properties due to growth, processing conditions etc. Therefore, another type of reinforcement with high cellulose content is of interest – regenerated cellulose fibers (RCF). These fibers are manmade, but unlike materials with fossil origin, they are made out of the natural polymer directly. RCF is continuous and therefore it is easy to arrange them into fabrics with stable orientation and geometry. But RCF fiber and also bio-based resin performance is highly non-linear with presence of very significant viscoelastic and viscoplastic component.

As basis, material model developed by Schapery [1, 2] was used in order to analyse time dependent behaviour of these materials. Model has been further modified to account for microdamage [3] (see. Eq. (1)).

\[
\varepsilon = d(\sigma_{\text{max}}) \left[ \varepsilon_0 + g_1 \int_0^t \Delta S(\psi - \psi') \frac{d(g_2 \sigma)}{d\tau} d\tau + \varepsilon_{\psi}(\sigma, t) \right].
\] (1)

In order to obtain all parameters needed for this model large number of experiments needs to be carried out. The numerous combinations of matrix and fibers are possible. Therefore it would be more convenient if material model is based on performance of constituents and test on composites should be performed only for verification of the model.

The main objective of this investigation is to predict mechanical behaviour of these composites and their constituents by generalizing existing models to capture their time-dependent behaviour. In order to identify and quantify parameters needed for the modelling, extensive damage tolerance tests as well as creep experiments are carried out.

REFERENCES

ESTIMATION OF THE QUALITY OF ANTICORROSIVE MULTICOMPONENT POLYMERIC COATINGS OF TECHNOLOGICAL EQUIPMENT FOR GASFIELDS OF JSC "GAZPROM"

J. S. Ryabets, N. V. Sorokina, and S. A. Soloviev

LLC Gazprom VNIIGAZ, Russia

According to the design decisions for the period of introduction in the build objects for Astrakhan and Orenburg hydrogen sulphide containing gas condensate deposits, anticorrosive protection of structural materials should be provided due to the retardants acting together with trade raw material. However, it has appeared ineffective, therefore as a method of protection of internal surfaces of the process equipment (devices clearing of sulfur and tubings) from corrosive-erosive deterioration was recommended application of protective coats: multi-componental adhesive polymeric and Gas thermal the metallized covatings.

In this work, various methodical approaches for definition of efficiency of protective properties of the internal multicomponent polymeric coverings applied in corrosive-excited environments in various operational conditions are considered. Their physical behaviour and residual physic-mechanical properties on the basis of holding a lot of characteristic kinds of tests (Tab. 1) are analyzed. In table 1, the list of a necessary minimum of the seeded characteristic parameters for an objective estimation of quality of internal coatings is resulted.

Table 1. The list of kinds of tests of internal polymeric and metal coatings

<table>
<thead>
<tr>
<th>No.</th>
<th>Test</th>
<th>The Standard on a test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hand inspection</td>
<td>GOST 8832 (ISO 1514), GOST 9.407</td>
</tr>
<tr>
<td>2</td>
<td>Estimation of thickness</td>
<td>GOST P 51694 method B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO 2808:1997</td>
</tr>
<tr>
<td>3</td>
<td>Estimation dielectric wholeness coatings</td>
<td>GOST 9.407</td>
</tr>
<tr>
<td>4</td>
<td>Adhesive durability</td>
<td>Appendix 4 API RP 5L2</td>
</tr>
<tr>
<td></td>
<td>- method of the Ō-shaped cut</td>
<td>ISO 2409:1998(B)</td>
</tr>
<tr>
<td></td>
<td>- method of trellised cuts</td>
<td>ISO 2409:1998(G)</td>
</tr>
<tr>
<td></td>
<td>- method breakoff</td>
<td>ISO 4624:1998</td>
</tr>
<tr>
<td>6</td>
<td>Resistance influence of a hydrochloric fog</td>
<td>GOST 9.401</td>
</tr>
<tr>
<td>7</td>
<td>Gas blistering</td>
<td>ISO 15741:2001(E)</td>
</tr>
<tr>
<td>8</td>
<td>Hydraulic blistering</td>
<td>ISO 15741:2001(E)</td>
</tr>
<tr>
<td>9</td>
<td>Scuffing</td>
<td>ISO 4060</td>
</tr>
<tr>
<td>10</td>
<td>Durability at direct (return) blow</td>
<td>ISO 6272</td>
</tr>
<tr>
<td>11</td>
<td>Thickness</td>
<td>ISO 2808-98</td>
</tr>
<tr>
<td>12</td>
<td>Adhesion a method normal breakoff</td>
<td>ISO 4624:1998</td>
</tr>
<tr>
<td>13</td>
<td>Definition of porosity</td>
<td>GOST 9.302-88</td>
</tr>
</tbody>
</table>

As a result, criteria of an estimation of quality and working capacity of polymeric adhesive internal coatings was defined and created special document of P Gazprom «The Basic requirements to internal and external protective coatings for the technological equipments of overground and building constructions.»
APPLYING OF PROBABILISTIC METHODS TO THE MATHEMATICAL SIMULATION OF TECHNOLOGICAL DEFECTS ARISING IN VACUUM INFUSION OF PRODUCTS MADE OF COMPOSITE MATERIALS

A. Safonov

National Composite Center of the Central Aero-hydrodynamic Institute, Russia

This report is related to description of mathematic models of technological defects arising at vacuum infusion of products made of composite materials. Infusion is a technological process of composites products manufacturing; during this process the material is formed at reinforcement impregnation by the resin owing to vacuuming. Vacuum infusion technology is used for production of different large-size composite structures: yachts body frames, wind power generator blades, bridge structures and etc.

The main task at infusion process simulation is impregnation system development. If the product is not fully impregnated during technological process or contains large quantity of technological defects, it will be rejected. In case of large-size structures production, it leads to heave financial and time losses.

The following specific technological defects take place at vacuum infusion: low degree of curing or unequal curing, uncompleted filling, dry spots and porosity. Computer programs on simulation of polymerization and impregnation were developed for mathematic description of defects arising.

Temperature field distribution inside the product was simulated by heat-conduction equation. Dynamic correlations were used for taking polymerization rate change into account. Resin flow through the reinforcement is simulated by Darcy low, which establishes line dependence between flow rate and gradient of applied pressure.

Assigned task was solved numerically with using of finite elements method (FEM) with applying of iterative methods.

Mathematic model parameters (permeability, adhesive viscosity and adhesive polymerization rate) essentially depend on stability of characteristics of base materials and technological parameters. It is impossible to take all mentioned factors into account in phenomenological models for model parameters. So the stochastic approach is considered for taking the variation of input parameters of base materials characteristics into account. This approach means that input data is given in view of random value with prescribed distribution. Then distribution function of output parameters of technological process is determined by Monte Carlo method: impregnation time, existence of non-impregnated areas and etc.

Examples of realization of this approach to simulation of defects arising in products of irregular shape are given.
THE INFLUENCE OF INHOMOGENEITY OF A GLASS-FIBER CHOPPED STRAND MAT ON THE LOCAL STRENGTH AND STIFFNESS OF A COMPOSITE

S. B. Sapozhnikov and A. V. Bezmelnitsyn

Department of Physics, South Ural State University, 454080, Chelyabinsk, Russia

Glass fiber chopped strand mats (GFMs) are the most perspective fillers of reinforced plastic in the industry where the price is most valuable. For increasing of resource efficiency, designers should pay attention to GFMs, which are used for heavily loaded parts of transport and building structures.

However, GFM is mainly inhomogeneous material in which there is no equal distribution of a filler according to the volume of a composite. In literature it is offered that a composite on the basis of GFM is isotropic and homogeneous in plane. Such hypothesis can be accepted because of simplicity and high value of safety factor for design of low loaded structures. But for structures with zones of stress concentration it is necessary to take into account real heterogeneity of the composite. Thus, the problem of research and modeling of inhomogeneous structure for further prediction of the strength of GFM composite under homogeneous and inhomogeneous stress states is really actual.

In this work the way of structural modeling of GFM is offered with the account of chaotic distribution of short fibers; the code was made using C++Builder for getting convenient user’s interface.

The code generates random distributions of short glass strand in a plane with a given value of aerial density. Volume fraction of filler in any point of a plate can be calculated with use of this data.

In the experimental part, the indentation of the surface of the plate was made on universal testing machine INSTRON 5882 by the steel ball (16 mm dia) in the nodes of grid to get the map of stiffness distribution in transversal direction. The maximum force on indenter was 2 kN under the condition of damage absence. Values of the average stiffness and the variation factor were defined. The plate was made by contact molding and composed from 4 layers of GFM (Ahlstrom M-600). Density of one layer was 600 g/m². Matrix is polyester resin (Polylite 440-M850) with peroxide hardener (Butanox M-50). Mathematical modeling helped to define the dependence of variation coefficient of transverse stiffness vs fiber volume fraction of filler for plates with arbitrary set of one-layer mats \((n \times 600 \text{ g/m}^2)\). The dependence of the variation coefficient vs quantity of layers in the composite was found.

The inhomogeneity of strain field on the surface of the four-layer plate was defined with the help of digital image correlation method. For this purpose Vic3D (the optic system of measuring the strain map) was used. The plate was clamped on one edge and loaded by 50 mm deflection on free edge. As a result, the maps of plate's surface strains in different directions were determined.

The comparison of the optical density of GFM with transverse stiffness and strain map heterogeneities were conducted.

It was shown that variation of the optical density doesn't correlate with both variation of transverse stiffness and strain map. But at the same time the stiffness distribution strictly correlates with the distribution of strain. Greater transverse stiffness corresponds to lower strain in the plane. It might be explained by the fact that for composites with low filler content there are linear relationships between elastic moduli and strength in the plane of reinforcement.
DELAMINATION OF COMPOSITE THICK-WALLED RINGS UNDER BENDING

S. Sapozhnikov and A. Shcherbakova

South Ural State University (National Research University), Russia

A development of the strength evaluation methods for thick-walled rings made of laminates nowadays is one of the actual engineering problems. As an example there can be considered a slow-moving plane bearing bush made of laminate. Required mechanical properties of such a product are supposed to be formed as a result of optimal combination of some process parameters such as an impregnation, winding, curing and so on. However, in practice during a manufacturing process, these parameters are often disregarded. That leads to some decreasing of the product stiffness and strength. In this regard, an evaluation of the product strength can be made including valuable information about samples delamination nature.

This work considers a thick-walled ring of inner diameter 120 mm, width 30 mm and wall thickness 6 mm made of laminate with a hot curing epoxy-phenolic resin as a binder and a plane weave glass fabric as a filler. That kind of rings represents a typical plane bearing part. To investigate a glass-reinforced plastic delamination the paper presents cut ring tension/bending tests (Fig.1). The tests were performed on the universal testing machine INSTRON 5882 with the use of the clamp tool T1058-53. As a result of testing the paper presents load vs clamp displacements function. The average value of the clamp displacements was about 25 mm and corresponding loads – 340 N at the fracture.

To evaluate the composite delamination strength there were used new FEA code developed in the environment MATLAB with the information obtained from the tests described above. A computational model takes into account a significant geometrical nonlinearity of structure and slipping of the ring surface along bearing rollers (Fig.1). The static side of this approach is based on Cauchy stress tensor $\sigma$, the geometric side – on the deformation gradient polar decomposition: $F = (\varepsilon + I) \cdot R$, where $R$ is rigid rotation tensor, $I$ is unit tensor and $\varepsilon$ is strain tensor which is related with stress tensor by a constitutive relation. As the constitutive relation the linear elastic law for an orthotropic material is used under plane strain condition and taking into account the cylindrical symmetry.

The calculations showed that the fracture load (340 N) obtained in the test corresponds the maximum transvers stress value about 3…4 MPa. This value is much less than the required strength in this direction (15…20 MPa). So that leads to the necessity of changing technology, polymer matrix or type of glass fabric sizing.
OPTIMIZATION OF THE STACKING-SEQUENCE OF LAMINATED COMPOSITE PLATES UNDER BUCKLING LOADS

J. Sedyono, H. Hadavinia, J. Deng, D. R. Marchant, and J. Garcia

School of Mechanical & Automotive Engineering, Kingston University London UK SW15 3DW

Laminated fibre reinforced plastic (FRP) composite materials have many applications in thin-walled structures such as an airplane fuselage. Such structures designing against buckling under compressive and shear loading and keeping the weight minimum is crucial for aerospace applications, which demand a high strength to weight ratio. Under compressive loading, structures are susceptible to buckling and as a result the structure could fail in its functionality. In this study, the maximum critical buckling load is sought for graphite-epoxy plates made from unidirectional plies under general multiaxial loading together with shear loading while the stacking sequence is changing. The optimum solution from different local and global optimization methods such as binary integer optimization, direct search method, genetic algorithm and simulation annealing are obtained using Matlab Optimisation Toolbox and the results from these methods are compared. From the numerical results, the advantages and disadvantages of each method are discussed. The methodology is then applied to optimally design buckling of a plate with circular and square cut-outs and the optimum design is compared with published experimental works.
BENDING BEHAVIOUR OF STRUCTURAL GLASS WITH DIFFERENT INTERLAYER LAMINATES

T. Serafinavičius, A. K. Kvedaras, and G. Sauciuvenas

Department of Steel and Timber Structures, Faculty of Civil Engineering, Vilnius Gediminas Technical University, Siauletekio ave. 11, LT-10223, Vilnius, Lithuania
tomas.serafinavicius@vgtu.lt

In modern building construction the glass should be considered not only as a clear to the light cladding, but also as a structural material for the load bearing elements. Structural application of the glass is laminated glass as a type of safety glass when interlayer laminate holds together two or more glass sheets in single piece after shattering [1]. Laminated glass is normally used when there is a possibility of human impact or where the glass could fall if shattered.

Over the last twenty years a number of experiments were performed in the world with structural glass usually investigating the behaviour problems of a single type of specimens or those at unique situation. The most of experiments were carried out to ensure continuous production of one party glass and laminates, and their results are not acceptable for needs of structural design generalization [2]. Therefore, in structural laboratories of Vilnius Gediminas Technical University the attempt to investigate behaviour of structural members made from different glasses and laminates as some types of composite elements was made. All specimens were made by professionals and by professional glass processing, tempering and laminating equipment which allowed ensuring comparable resistance analysis of structural glass as composite elements.

This paper presents the results of experiments on bending strength of structural laminated glass. In the experiments three different 1.52 mm thick interlayer laminates were used: Polyvinyl butyric (PVB), Ethylene vinyl acetate (EVA), DuPont’s SentryGlas (SG) and 6 mm thick tempered Soda-Lime-Silica Glass. These types of laminates were chosen because there is a wide range of their possible applications also in a construction practice. Into the common interaction between the structural glass sheets and interlayer laminate could be regarded as happening in a composite member which may be represented as structural load bearing element like plate, column or beam in public or residential buildings.

Bending tests were carried out in accordance with the specimen supported at two points applied to standard EN 1288-3. Tests have been carried out until failure and deflections at the middle of span and at the supports, as well as load values, tensile and compressive strains on the upper and bottom surfaces of the glass were measured. The measurements of slide of different types interlayer laminates between the two structural glass sheets were carried out too. In the paper an analysis of the experimental results is given presenting a comparison between resistance of glass composite panels with various laminates and the monolith glass sheets. That allowed evaluating more acceptable composition of laminated structural glass panels.

REFERENCES

PREDICTION OF STRAIN AND STRENGTH PARAMETERS OF ASPHALT CONCRETE

S. V. Shilko

V.A. Belyi Metal-Polymer Research Institute of NAS of Belarus, Gomel

The description of mechanical behavior of the asphalt and concrete material for road coatings is developed using experimental and theoretical methods. Material is assumed as the disperse-filled composite. The dependences of effective Young modulus and strength on a volume fraction of rigid filler (rubble) are obtained. The approach to an estimation of degradation of structure and mechanical properties of binding material of asphalt concrete has been developed. For calculation of strain and strength characteristics the approximate analytical solution of a problem about uniaxial compression of cylindrical samples in frameworks of elastic and viscoplastic models of a material with nonlinear viscosity has been received.

Tests of samples for asphalt binding material as well as asphalt and concrete composites on low-cycle fatigue in different modes of soft loading are carried out (Fig. 1).

By identification of model of deformation, the dependences of Young modulus, yield stress, coefficient of viscosity and parameter of speed sensitivity for asphalt binding material from number of a cycle are received. The description of degradation process in terms of energy dissipated per cycle of loading and new accelerated testing method for the fatigue strength prediction of asphalt and concrete composites have been proposed.
Aspen trees, along with pine and birch ones, provide the highest wood yield in Latvia. By-products that are formed during forest exploitation and wood mechanical processing are used mainly for energetic needs. At the same time, aspen lignocellulosic by-products can serve as the feedstock for obtaining value-added products with purposeful targets. Technical lignins have found a wide application as a renewable, low-cost resource for obtaining surface active agents, which can regulate surface tension at different interfaces, including dispersion systems. In the present work, using aspen sawdust, a by-product of Latvian wood mechanical processing, soda aspen lignin was obtained by the laboratorial delignification process. Delignification parameters were the following: NaOH concentration 4.0%, temperature 165°C, time 1.5 h, hydromodulus 1:7. It has been found that, with diminishing pH of the soda lignin solutions from 12.0 to 5.5, their values of conductivity, as well as specific and intrinsic viscosity, considerably decrease, while its surface tension at the air-water interface changes to a lesser extent. For the purpose of improving the surface activity, the obtained soda aspen lignin was modified by the polyelectrolyte interaction with polyethyleneimine (PEI), having different molecular mass, in aqueous reaction mixtures with obtaining the new polymeric products, namely, the lignin-based non-stoichiometric interpolyelectrolyte complex (LNIC) [1-3]. The obtained LNIC composition was characterised by different charge ratio between soda lignin and PEI. The interfacial tension of the reaction mixtures at the air-water interface was measured using a tensiometer “Krush”. Viscosity was determined by an Ubbelohde viscometer. The sizes of the obtained LNIC particles were measured by dynamic light scattering, using Malvern Nanosizer NZ. It has been found that, with increasing content of PEI in the reaction mixtures, its molecular mass and the time of the interaction between soda aspen lignin and PEI, the specific and intrinsic viscosities of the reaction mixtures decrease, but the surface activity of the LNIC particles at the water-air interface essentially increases. The values of the sizes of the non-stoichiometric interpolyelectrolyte complex particles have demonstrated their considerable dependence on the molecular mass of PEI and the time of its interaction with soda lignin in the reaction mixtures, while the changes in the values of zeta potential for the particles of the LNIC, with increasing molecular mass of PEI, were pronounced to a lesser extent. Depending on the content of PEI and the time of the interaction between soda lignin and PEI in the reaction mixtures, the averaged sizes of the formed polycomplex particles vary in the ranges 161 – 552 nm and 65 – 469 nm for high and low molecular PEI, respectively.

REFERENCES:
COMPARATIVE EFFECT OF POLYALUMINIUM CHLORIDE AND ITS COMPOSITION WITH SULPHATE ALUMINIUM ON WOOD PROCESSING WASTEWATER COAGULATION

G. Shulga1, J. Brovkina1, S. Vitolina1, S. Ostrovska1, J. Ozolins2, and R. Neilands2

1Latvian State Institute of Wood Chemistry, Riga, Latvia
2Riga Technical University, Riga, Latvia

Veneer production includes the hydrothermal treatment of wood in special basins. The wastewater of these basins has a high contamination, because it contains wood originated impurities such as lignin, hemicelluloses and extractive substances, forming waste wood biomass (WB), which is responsible for the high values of chemical oxygen demand (COD) and colour degree of the wastewater. Keeping in mind the zero waste policy for rational use of bioresources and the possible usage of waste wood matter in practice, it is very important to remove quantitatively the formed biomass from the basin’s wastewater. Chemical methods of wastewater treatment with inorganic coagulants are often applied, and aluminium salts as effective coagulants take a honourable place among them. Polyaluminium chloride (PAC) is a very effective, but expensive coagulant, which is used for the treatment of drinking water. In water, PAC undergoes hydrolysis and polymerization reactions, resulting in the formation of polycations (e.g. $[\text{Al}_4\text{O}_4\text{Al}_{12}(\text{OH})_{24}(\text{OH}_2)_{12}]^{7+}$ ), which represent polynuclear aluminium complexes. The coagulation action can be divided in two distinct mechanisms: charge neutralization of negatively charged impurities by the formed polynuclear aluminium complexes and adsorption of impurities at an amorphous complexes precipitate. The aim of the study was to compare the effectiveness of biomass extraction from the model wastewater of the wood hydrothermal treatment, using separately PAC and its different compositions with a cheaper coagulant such as $\text{Al}_2(\text{SO}_4)_3$. The hydrothermal hydrolysis of wood was done in a weak alkaline medium at the modulus 1/50, 90°C for 4 h. The obtained birch wood hydrolyzate, imitating the wastewater, contained 1400 mg L$^{-1}$ of dry solids and had the pH 9. Polyaluminium chloride (POLYPACS-30), $\text{Al}_2(\text{SO}_4)_3 \cdot 16 \text{H}_2\text{O}$ and their compositions were used for WB recovery. The coagulation efficiency was defined after 2 h of the system settling and filtration. The effectiveness of the wastewater purification was determined at the pH 6 and a dose of 100 mg L$^{-1}$, which were the optimal for PAC. COD and the colour of the purified solution were determined by ISO 6060:1989 and ISO 7887:1994, respectively. The efficiency of the wastewater treatment was calculated in terms of removal (%), based on the initial and final values of the content of WB, lignin, as well as COD and colour index. It was found that the efficiency of the wastewater treatment sufficiently depended on the mass ratio of PAC to $\text{Al}_2(\text{SO}_4)_3$ in the composite coagulant and had a non-linear dependence on the coagulant composition. At the optimal composition of the composite coagulants, the increase in WB removal was 33% and 47% relative to PAC and $\text{Al}_2(\text{SO}_4)_3$, respectively, the increase in lignin removal varied from 28% to 43%, COD diminished from 401 mgO L$^{-1}$ to 368 mgO L$^{-1}$, but colour removal increased from 24% to 35%. The additional usage of ozonation after the coagulation purified the wastewater to a greater extent in comparison with the coagulation alone. According to the obtained results of dynamic light scattering, the wastewater, ozoned during 1 h at a flow rate of 5 g h$^{-1}$, after coagulation with the composite coagulant, having the optimal composition, was characterized by the narrow unimodal particle size distribution with the particle size < 100 nm, the zeta potential of which had low positive values. Thus, it was established that the composite coagulant, which was cheaper than PAC, exhibited better coagulation performance, when compared with simple PAC in terms of the parameters of wastewater purification.
HYBRID-FIBRE-REINFORCED CEMENTITIOUS COMPOSITES

E. R. Silva¹,², J. F. J. Coelho², and J. C. Bordado¹

¹Dept. of Chemical Engineering, Instituto Superior Técnico - UTL, Lisboa, Portugal
²Dept. of Chemical Engineering, Universidade de Coimbra, Coimbra, Portugal

Cement-based materials are one of the most used in construction. The main drawbacks of these materials are their brittle properties. Therefore, when subjected to stresses, cracks can appear and spread, leading to the deterioration of their mechanical properties. Recent studies on hybrid fibre-reinforced cement systems revealed promising anti-cracking performances [1]. Nevertheless, these newly systems are in an embryonary stage of research and few hybrid fibre systems have hitherto been studied. The present work reports on the mechanical properties of newly polypropylene/polyethylene (PP/PE) hybrid fibres (HyF) reinforced-cement matrices. Fibres properties (aspect ratio, distribution, surface morphology) and superplasticizer effects on the mechanical behaviour of the developed hybrid fibre-reinforced composites (HyFRC) were studied. The results revealed promising mechanical performance of HyFRC. Improvements of 40±2% on compressive and flexural strengths were obtained for 24 mm HyF length-reinforced composites at fibre volume fractions as high as 2.9%, considerably higher than the standard fibre volume (2%) of existing premix premixing processes [2]. The enhanced mechanical performances were attributed to the microcrack distribution system provided by the HyF, and to mechanical interlocking between fibres/cement interfaces (Fig. 1-a) promoted by the peculiar high fibres’ section area, rugosity (furrowed surfaces) and fibrillation ability (Fig. 1-b). Morphological observations of fibre/cement interfaces also evidenced a multiple cracking mechanism, promoted by fibres microcracking arresting action. This research revealed that the innovative polyethylene/polypropylene hybrid fibres can make an important contribution for boost confidence in the new generation of HyFRC and their potential enhancement of cement-based construction materials.

![Fig. 1. Fibre/cement interface (a); PP/PE hybrid fibres (b).](image)

REFERENCES

PREDICTION OF THE FLEXURAL BEHAVIOUR OF STEEL FIBER REINFORCED CONCRETE

U. Skadiņš and J. Brauns

Dept. of Structural Engineering, Latvia University of Agriculture, LV-3001, Jelgava, Latvia
e-mail: ulvis.skadins@llu.lv

Steel fibre reinforced concrete (SFRC) can be characterized by quasi-brittle matrix, relatively ductile fibres, and by interfaces that can transfer important shear forces between the constituents. Adding fibers there is possibility to increase the material stiffness, flexural and tensile strength, impact resistance, as well as obtain a ductile behaviour in cracked material.

The flexural behaviour of SFRC members can be determined during direct loading. Nevertheless, in the structural design of fibre-reinforced elements and in order to determine the possibility to use the material in a cracked range [1, 2], methods for prognostication of material properties in flexure have to be developed. The approach is proposed to determine the inelastic behaviour of flexural SFRC members.

On the basis of material characteristics in direct uniaxial tension and compression of SFRC mathematical models for prognostication of material behaviour in flexure is worked out. The reinforced element as a two-layered system is treated and in the cracked range the action of quasi-plastic tensile stresses is considered. Based on the experimental data and codes [3], idealized stress-strain diagrams in tension and compression are suggested.

Forth-point bending tests of SFRC beams containing different types of fiber with the fiber volume fraction of 1.0% were performed. The applied force, midspan deflection, and the strains on both compressed and tensioned sides were recorded. Proposed bending moment $M$ for beam with dimensions $b \times h$ was determined on the basis of both tensile $\varepsilon_t$ and compression $\varepsilon_c$ strains and first moments of areas under tensile and compression diagrams $S_1$ and $S_2$, respectively:

$$M = \frac{bh^2}{(\varepsilon_t - \varepsilon_c)^2} [S_1(\varepsilon_t) - S_2(\varepsilon_c)].$$ (1)

Obtained moment-curvature and stiffness-moment relationships were compared with the ones derived from the proposed model. The analytical predictions showed a good agreement with the experimental data.

REFERENCES

The paper is concerned with the vibration problem for the lattice composite adapter (attach fitting) (Fig.1) which provides the interface between the spacecraft and the rocket launcher and has the form of a cylindrical or conical shell consisting of helical and circumferential ribs and made of unidirectional carbon-epoxy composite material by filament winding. The separation problem for a spacecraft attached to the preliminary compressed and working as a spring fitting is studied. The axial and transverse natural vibrations of the fitting with a spacecraft are considered. Various dynamic models of the fitting are considered, and the simplest of them which ignores the fitting mass in comparison with the spacecraft mass is recommended. Dynamic properties of actual spacecraft are studied and confirm the technical possibility of the proposed separation method.

Fig. 1. Lattice Composite adapter.

REFERENCES

RESIDUAL STRESS IN MOISTURE-SENSITIVE LAMINA

J. Šliseris and K. Rocēns

Department of Structural Engineering, Riga Technical University, Riga, Latvia

The moisture sensitive materials are commonly used in load bearing or covering structures. One of the most popular material in this class of material is wood. Plywood is very common wood material. The plywood elements could be manufactured with symmetrical or unsymmetrical macro-structure with respect to mid-surface. The plywood sheet with unsymmetrical macro-structure obtains curved shape (negative Gaussian curvature) because of orthotropic moisture expansion properties of veneer.

The unsymmetrical macro-structure could be used to create a new manufacturing technology (there could be used a standard manufacturing equipment that are used in manufacturing of flat plywood sheets) of curved plywood sheets. A several questions arise according to this kind of sheets. The environment moisture conditions are time dependent and therefore the shape of the sheet is also time-dependent. Significant residual stresses arise when the sheet is curved with moisture difference. The plywood viscous-elastic-plastic properties contribute the change of stress-deformation and shape.

The behaviour of plywood sheet with unsymmetrical structure is numerically simulated. The simulation is done by solving coupled moisture diffusion, temperature conductive and stress-deformation problems. Deformations and displacements are large and therefore geometrically nonlinear problem are solved [1]. From a material constitutive model point of view, the material model presented in this paper is composed of five deformation mechanisms which provide an additive decomposition of strain into elastic response, hygroexpansion, viscoelastic creep, recoverable mechanosorption and mechanosorptive irrecoverable creep [2,3,4]. The moisture diffusion in transversal direction of plywood sheet is analyzed using Fick’s law [5]. Temperature conduction is analyzed by Fourier’s law.

The results of numerical simulation are verified by results of physical experiment. There are obtained the moisture diffusion coefficient in transversal direction of plywood by physical experiment. The results showed that the relaxation of residual stress produce a decrease of curvature of 3-ply sheet more than 20 %. The moisture diffusion kinetics of plywood is different comparing to the same density wood.

REFERENCES
COMPARISON OF FRACTURE ENERGIES OF EPOXYPOLYSULFONE MATRICES AND UNIDIRECTIONAL COMPOSITES BASED ON THESE MATRICES

V. I. Solodilov, R. A. Korokhin, Yu. A. Gorbatkina, and A. M. Kuperman

Semenov Institute of Chemical Physics of Russian Academy of Sciences, Kosygin Str. 4, Moscow, Russia

The paper compares fracture energies of modified epoxy matrices and unidirectional glass (GFRP), carbon (CFRP) and organic (OFRP) fiber reinforced plastics based on these matrices.

Unidirectional composites were fabricated by winding of reinforcing fibers: the RVMPN 10-400 glass fiber (R&P association “Stekloplastik”), Sigrafil C type carbon fiber (SGL Carbon Group), and Rusar aramide fiber (JST “Khimvolokno”). Epoxy-polysulfone compositions were used as matrices containing from 5 to 20 wt. % of the PSK-1 polysulfone. The matrices were cured with triethanolaminotitanat.

After cure, ring composite specimens were cut to obtain the segments for shear tests (the three point short beam test) and fracture toughness tests (delamination of a double cantilever beam). Test specimens were also prepared from cured matrices: double-T shape specimens were used for the determination of crack resistance of the matrices $G_{IR}^M$ (with the aid of splitting of a double cantilever beam with a notch) and rectangular cross-section specimens were used for the determination of fracture energy $A_F^M$ (three point load mode) and impact bending strength $\sigma_b$.

It is shown that GFRP, OFRP and CFRP have different failure mechanisms under shear, which are likely related to the fibers nature. Delamination energy of reinforced plastics is mainly determined by the matrix impact strength.

Fracture toughness $G_{IR}$ for GFRP, OFRP and CFRP monotonically increases with the increase of the polysulfone content in the matrix. Marked growth of $G_{IR}$ is observed for 10–20 wt. % of polysulfone. Crack resistance increases by two times for the composites under investigation. In the case of the matrices, $G_{IR}^M$ growth starts when PSK-1 content exceeds 5 wt. %, and at 15–20 wt. % of PSK-1 the values of $G_{IR}^M$ increase by four times. Fracture toughness of GFRP and OFRP is 3–4 times higher, then for CFRP with any concentration of polysulfone. We observed a correlation between crack resistance of reinforced plastics and crack resistance polymer matrices in all investigated cases. The growth of the values $G_{IR}$ with increasing $G_{IR}^M$ is more rapid for GFRP and OFRP then for CFRP.
MECHANICAL AND RHEOLOGICAL PROPERTIES OF THERMOPLASTIC ELASTOMERS WITH A RUBBER POWDER

D. V. Solomatin, O. P. Kuznetsova, and E. V. Prut

Department of Polymers and Composite Materials, Semenov Institute of Chemical Physics, Russian Academy of Sciences, Moscow, Russia

e-mail: evprut@center.chph.ras.ru

Recycling rubber by the preparation of rubber powder (RP) by grinding is potentially an effective means for reducing the environmental problem of waste rubbers. One of the promising methods developed in the last two decades is the high-temperature shear deformation. The method of high-temperature shear deformation (HTSD) is based on the grinding of a material in a complex strained state by the action of uniform compression pressure and shear forces under elevated temperatures. This method is available for the production of finely rubber powder.

Major goal of this work is to study the influence of the effect of RP on the mechanical and rheological behaviors of thermoplastic elastomers (TPE) and thermoplastic vulcanizates (TPV).

The polymers used in this study were iPP, commercial oil-free ethylene-propylene-diene rubber EPDM Dutral TER 4044 and oil-extended EPDM Dutral TER 4334 and EPDM Dutral TER 4535 (Polimeri Europa, Italy).

EPDM vulcanizates of different crosslink densities were obtained by varying the amount of sulfur in the recipes, changing the ratio of sulfur to accelerator system.

Rubber powder was prepared from EPDM vulcanizates with different crosslink density. Sieve analysis showed that for all types of RP had a majority of particle size of 0.315<d<0.63 mm. The increasing of crosslink density of the rubber vulcanizate decreased percent of particles size of d>0.63 mm, while percent of particles size of d<0.315 mm increased. The particle size distribution is independent on the crosslink density of EPDM vulcanizates. The RP particles have an asymmetrical shape. Two characteristic regions with a distinct boundary are observed at the surface of particles: a region of plastic fracture with highly developed surface and the region of brittle fracture with a smooth surface. The increasing of sulfur concentration in the original EPDM vulcanizates leads to a decrease in the plastic fracture on the RP surface.

Blends were prepared in a Brabender Plastograph EC mixer at 190°C. The sulfur accelerator system was used as crosslinking agents of the elastomeric phase. Testing samples of PP/EPDM blends with EPDM unvulcanized and dynamically vulcanized were pressed 10 min at 190°C.

The stress-strain behavior was carried out on testing machine Instron-1122 at room temperature with a constant upper crosshead speed 50 mm/min. It is found that the partial replacement of EPDM on RP in TPE and TPV leads to degradation of mechanical properties.

The rheological behavior of TPEs and dynamically cured TPVs with RP was determined by capillary rheometer. It is found that the addition of RP into elastomeric phase of TPE increases its viscosity, while the addition of RP into elastomeric phase of TPV decreases its viscosity. Also, it was shown that the performance of TPE and TPV with RP in depends on particle size, surface area, and composition.
FINITE ELEMENT ANALYSIS OF THE INTERFACIAL FRACTURE TOUGHNESS OF HONEYCOMB SANDWICH BEAMS FROM TILTED SANDWICH DEBOND TESTS

W. Song and Z. J. Ma

Dept. of Civil and Environmental Engineering, the University of Tennessee Knoxville, U.S.A

Sandwich structures with honeycomb cores are now becoming more and more popular in civil engineering. The debonding of the interfaces between face sheets and cores is one of their major failure modes. The face sheets and cores are usually made of different materials and the debonding of bimaterial interfaces are mostly due to mixed mode loading. Therefore it is vital to consider the mode mixity when investigating the interfacial fracture toughness. This paper focuses on the debonding of a specific honeycomb sandwich structure with flat and sinusoidal cores under mixed mode loading. Interfacial fracture toughness is investigated through tilted sandwich debond (TSD) tests and finite element analysis (FEA). Parametric study through FEA is conducted to analyze the influences of tilt angles, specimen geometry and crack length on the mode ratios. Because energy release rates are usually applied in the virtual crack closure technique (VCCT) and cohesive zone modeling (CZM), the mode mixity is expressed in terms of the ratios of energy release rates. After the parametric study, the specimens with certain initial crack length which allow crack propagation with fixed mode ratios in the TSD tests will be proposed. Besides, this paper also discusses the potential data reduction method for the determination of the interfacial fracture toughness of this honeycomb sandwich structure from TSD tests. Several parameters, such as interfacial fracture toughness, specimen geometry and crack length are considered to study the effects of geometric nonlinearity on the data reduction. This paper eventually proposes some conclusions which may facilitate the design of actual TSD tests in the future.

REFERENCES

STIFFNESS, STRENGTH, AND TOUGHNESS CHARACTERISTICS OF A UNIDIRECTIONAL FLAX-FIBER COMPOSITE

E. Spārniņš, J. Modnīks, and J. Andersons

Institute of Polymer Mechanics, University of Latvia, Riga, Latvia

During the last decades plant fibers have been extensively studied as a replacement of their synthetic counterparts in polymer composites. Their main advantages are low density and price. Stiffness of the flax fibers, which appear the most promising currently, is comparable to that of glass fibers. Unfortunately, the strength and even specific strength reported is always lower than that of glass. Recently, a new type of materials has been developed: epoxy resin prepregs with UD oriented flax fibers as the reinforcement. These materials appear very promising, although the manufacture costs are significantly higher, but the low density benefits are retained. Other potential advantages are due to material with oriented fibers and potentially more competitive strength and a new (for natural fibers) and important possibility to make optimal composite lay-ups for specific applications. In addition, flax fibers have a high vibration damping potential which can be exploited in load-bearing applications.

Design of the laminate lay-ups of any complexity is always based on the ply properties. The aim of the present study is to determine the in-plane mechanical properties of a unidirectional flax-fiber composite laminate. The material studied was a unidirectional flax-fiber/epoxy composite. It was manufactured combining four plies of the prepreg produced by LINEO and designated as FlaxPly UD180. Curing was performed using a thermostress at 120 °C and 3 bar pressure, using the vacuum bag technology. Rectangular specimens were cut out of the composite plates at different angles with respect to the fiber direction. In some of the specimens, a notch was made along the fibers. The specimens were tested in tension, and the stiffness and strength in the principal material directions and the intralaminar fracture toughness for cracking along the fibers were evaluated.
EXPERIMENTAL STUDY ON THE EARLY-AGE CREEP AND SHRINKAGE OF PVA FIBER-REINFORCED HIGH STRENGTH CONCRETE

A. Sprince¹, L. Pakrastinš¹, A. Korjakins², G. Shakhmeno², and G. Bumanis²

¹Department of Structural Engineering, Riga Technical University, LV-1048, Riga, Latvia
²Institute of Materials and Structures, Riga Technical University, LV-1048, Riga, Latvia

Last three decades scientists and concrete technologists have been working on the development of new types of concrete. Newly elaborated material provides improved mechanical and physical properties. Creep and shrinkage of high strength concrete are complex problem, especially at very early ages, because of its brittleness and sensitiveness to cracking. The aim of this experimental study was to determine elastic and time-dependent deformations of polyvinyl alcohol (PVA) fibers reinforced high performance concrete. The experimental studies of shrinkage and early age creep were performed. High performance concrete mix with three different amount of fiber were developed and prepared. Concrete specimens were tested in a controlled constant temperature and with a constant level of moisture. The specimens were put into a creep lever test stand (see Fig. 1) and subjected to a uniform, constant compressive load. Stress levels were calculated from compression strength results after 1, 4, 7 and 14 day curing. During all tests other specimens were measured for shrinkage. The compression strength and modulus of elasticity of HPFRC concrete specimens were determined and compared with control samples without fibers. The creep deformations were found to decrease with concrete aging and time. The total lowest creep deformations, as well as the highest creep strain, were exhibited by the reference specimens.

![Fig. 1. Creep test lever stand.](image-url)
EFFECT OF NANOTUBE ADDITION ON TENSILE, THERMAL AND TRANSPORT PROPERTIES OF POLY(ETHYLENE-VINYL ACETATE) COPOLYMERS

O. Starkova¹, S. T. Buschhorn², L. A. S. A. Prado², and K. Schulte²

¹Institute of Polymer Mechanics, University of Latvia, LV-1006 Riga, Latvia
²Institute of Polymers and Composites, Technische Universität Hamburg-Harburg, D-21073 Hamburg, Germany

Thermoplastic polymers are widely used as engineering materials due to their thermal stability and stiffness together with the relatively easy processing and light weight. The mechanical and thermal properties of thermoplastics can be significantly improved by the addition of carbon nanotubes (CNTs) due to outstanding mechanical and thermal stabilities of these nanoparticles. Moreover, mixing of polymers and CNTs opens ways to develop engineering-flexible composites with significantly improved electrical properties. The aim of the present study was to investigate the effect of CNT addition on tensile, thermal and transport properties of Poly(ethylene-vinyl acetate) (EVA) copolymers and to evaluate the properties changes due to hydrothermal ageing.

Two commercially available copolymer resins Elvax® 420 and Elvax® 450 (DuPont™), neat and filled with 15 wt.% of pristine multi-wall CNTs (C150P, Baytubes), were studied. The mechanical and thermal properties of “as produced” samples were compared with those conditioned in water at $T = 50^\circ$C for three weeks up to saturation.

Addition of nanotubes noticeably affected tensile behaviour of the EVA nanocomposites. The elastic modulus and stress at break of the nanocomposites increased for 200 and 50% compared to the neat copolymers, respectively. The mechanical characteristics of all investigated materials were not significantly altered by varying the applied strain rate from 2 up to 200 mm/min. A study of the materials by differential scanning calorimetry (DSC) showed the broad melting transition of the neat EVA indicating to a poor crystalline order, as expected. Melting and glass transition temperatures of both EVA copolymers were practically not altered by the addition of CNTs. Contrarily to almost unchanged melting behaviour of Elvax® 420 copolymer, crystallinity of EVA450/CNT composites reduced for about 20%. An increase of sorption capacity along with a significant decrease of the rate of diffusion was observed for the nanocomposites compared to the neat EVA. The sorption curves could be fitted using the Fick's diffusion model. Hydrothermal ageing noticeably affected the elastic properties of all materials, while the ultimate characteristics remained practically unchanged. Interestingly, the decrease in the elastic modulus of the neat EVA is almost two times greater than for the nanocomposites. By comparing DSC scans of “as produced” and conditioned samples, it is determined that the plasticization effect due to presence of water is negligible and glass transition temperatures remained practically unchanged for all samples. However, the effect of hydrothermal ageing caused a decrease of the melting temperature and a low crystallinity of EVA copolymers and their nanocomposites.
STRENGTH – DEFORMATION CHARACTERISTICS OF SLIGHTLY CROSSLINKED POLY(VINYL ALCOHOL) GELS

J. Stasko¹, L. Berzina – Cimdina¹, and M. Kalnins²

¹Biomaterials Innovation and development centre, Riga Technical University, LV-1007, Riga, Latvia
²Institute of Polymer Materials, Riga Technical University, LV – 1048, Riga, Latvia

Cryogenically crosslinked poly(vinyl alcohol) (PVA) gels are popular research objects due to broad spectra of potential practical application mainly in bio-medical area: tissue-engineering, cartilage reconstruction, materials for artificial skin, bioadhesive and mucoadhesive systems, drug delivery systems.

Stress-strain characteristics of water swelled (up to equilibrium swelling degree α) PVA gels prepared by freezing/thawing technique were studied in present work. Small number of freezing/thawing cycles Nc (1 – 3) was used, thus providing low crosslinking density (high values of average molecular weight between crosslinks M_c, calculated by use of flory-rehner approach) and as a consequence – very high swelling degree in water.

Due to low strength of swelled gels, strip shaped gel samples (110×20×5 mm) with specially reinforced ends were prepared for tensile tests. Universal test machine Zwick Roell BDO-FB020TN was used to determine tensile stress σ – relative elongation ε relationships up to ductile fracture of the sample with rate of cross-heads motion 50 mm/min at 20°C at room temperature. Several characteristics were fixed from respective σ(ε) curves: tensile strength σ_B, elongation at break ε_B, specific strength σ_B/ρ (where ρ - density of gel), expressed as self support length, efficient modulus of elasticity (calculated by MathCad program) Eq. (1) below:

\[ E_ε = \frac{dσ}{de}|_{ε=const} \]  

as function of elongation ε, average value of modulus \( E_ε \) calculated from the function \( E_ε(ε) \), as well as “provisional” modulus Eq. (2):

\[ E^* = \frac{σ_B}{ε_B}. \]  

Compression tests of gel samples were performed on rectangular gel samples (10×10×10 mm) by use of special testing device which allows measuring of force with accuracy ± 0.01 g and displacement – with accuracy ± 0.01 mm in quasy-static conditions. Values of respective compression modulus \( E_C \) and \( E^*_C \) was determined.

As an example, structural and stress-deformation characteristics of swelled gel prepared from 15 % PVA water solution are shown in the Table 1.

Table 1. Some structural and stress-deformation characteristics of gels (designations in text)

<table>
<thead>
<tr>
<th>n_c</th>
<th>α</th>
<th>M_c x 10^4</th>
<th>Tensile test</th>
<th>Compression test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>( E_c,\ MPa )</td>
<td>( E^*,\ MPa )</td>
</tr>
<tr>
<td>1</td>
<td>32</td>
<td>130</td>
<td>0.007</td>
<td>0.006</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>26</td>
<td>0.036</td>
<td>0.035</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>18</td>
<td>0.053</td>
<td>0.053</td>
</tr>
</tbody>
</table>

The relationships between these characteristics and structure of gels are discussed.

Acknowledgements. This work has been partly supported by the European Social Fund within the project “Multidisciplinary Research in Biomaterials Technology of New Scientist Group”, No.2009/0199/1DP/1.1.1.2.0/09/APIA/VIAA/090.
INTELLIGENT CHARACTERIZATION OF MATERIALS BY USING MACHINE INTELLIGENCE

V. Shtrauss, A. Kalpinsh, and U. Lomanovskis

Institute of Polymer Mechanics, University of Latvia, Riga LV-1006, Latvia

For innovative materials, such as advanced composite materials and nano-structured multi-functional materials, there is an increasing need for determination of physical and mechanical properties of materials, as well as various operation parameters within the whole material/product life cycle. Because of complexity of such materials, abilities of commonly used non-destructive methods often are not sufficient longer. This requires to change the role of non-destructive testing and evaluation and to expand non-destructive technologies beyond their historical mission of detecting macroscopic defects in materials/products.

Measurement of materials properties is often referred as materials characterization. Thus, non-destructive techniques applied to materials characterization lead that specific quantitative information of interest shall be extracted from the measurements. In this case, the directly measured quantities are not the desired measurands, but the desired measurands are linked with the directly measured quantities in some way. In mathematical context, extraction of the desired properties and parameters of materials from the measurements is an inverse problem with well known complexities of solution due to the fact that experimental data sets are inevitably corrupted by noise, discretely sampled and incomplete (truncated). However, the main difficulty is that the functional relationship between the measured quantities and the desired measurand estimates usually are not known.

In the present report, the research results are represented obtained in developing methodology and instrumentation for non-destructive materials characterization based on machine intelligence carrying out so-called learning-from-examples algorithms. To reconstruct the functional relationship between the directly measured quantities and the desired measurand estimates, an automatic learning subsystem is integrated in the measurement system based on artificial neural network implemented in the form of multi-layer feed-forward network trained by back propagation.

A methodology of non-destructive materials characterization is developed, which includes: (i) gathering representative training and validation data sets from databases or by carrying out measurements on material specimens having various values of the parameter (property) of interest, (ii) designing the algorithm for determination of values of the parameter of interest by training a neural network of a selected architecture with the gathered training data set, (iii) validating the designed algorithm by processing the gathered validation data set by the trained neural network, (iv) material characterization (determination of the desired parameters) by carrying out measurements on the material under study and processing the measurement data by the designed algorithm (neural network).
SELF-MONITORING OF FIBRE-REINFORCED COMPOSITES: VISUAL RESPONSE TO THE EXTERNAL INDENTATION

O. Strekalova, S. Vidinejevs, and A. Aniskevich
Institute of Polymer Mechanics, University of Latvia, Riga, LV-1006, Latvia

Nowadays, fibre-reinforced composites (FRCs) with epoxy matrix are widely used in many applications in engineering and construction. Unfortunately, internal damage of such material is not always visible and use special equipment is necessary for damage monitoring. Using the self-monitoring material as a sensor of its own damage is the optimal way to implement a structural health monitoring.

In the tested glass fibre reinforced epoxy composite, damage indicator (biomimetic, ‘bruisable’ prepreg) is represented as a fabric, impregnated with UV cured mixture of water emulsions of microencapsulated leuco day (A), color activator (B) and epoxy-modified polyurethane acrylic polymer (C). It is located in the upper layer of composite and damage visualization is provided by changing the colors on the spot under load, suchwise the embedded biomimetic function provides damage visibility like a ‘bruise’ in the human body [1].

The present research is targeted to develop a fibre reinforced epoxy composite with visual response to the external indentation.

This has been achieved by searching 1) optimal component ratio in damage indicator for (C) component and 2) optimal UV curing time for impregnated fibreglass fabric.

Visual response of damage under load in FRC was measured from photos of tested samples using original script in Mathcad for digital image analysis. This method allowed us to estimate visual response to indentation.

The mixtures of (A), (B) and (C) components were prepared using different ratio of (C) component. The ratio of (A) and (B) was fixed 6/3, respectively. Fibreglass fabric pieces were homogeneously impregnated in the prepared mixtures and cured under UV lamp. Ready prepregs, with (C) component concentrations from 6/3/0.2 to 6/3/4, were tested by quasi-static compression tests. An intensity of the colored response was estimated by digital image analysis. It was experimentally established that the most intensive colored response under load was obtained using 6/3/2 components ratio for (A), (B), (C).

The mixture of (A), (B) and (C) components were prepared using certain ratio of all components 6/3/2, respectively. Fibreglass fabric specimens were homogeneously impregnated in the prepared mixture and UV cured with different curing time. Using digital image analysis, the optimal UV curing time was found as 15 min for a given intensity.

Present results permit to produce self-monitoring FRC with improved visual response to impact damage. Use of this material guaranties visual response appearance after specific load and gives opportunity timely replace the damaged part.

REFERENCE

THE S-N EQUATIONS OF TYPICAL AIRFRAME COMPOSITE ELEMENTS

V. Strizhius

Aerospace Engineering Department, Progresstech Ltd., 125362, Moscow, Russia

It is known that for similar types of details loaded in-plane, airframe composite details staying within design rules have much greater durability than metals. However, it should be noted that the durability of composite elements is not limitless and the problem of durability of composite elements should be dealt with in full.

S-N curves are used as a basic tool to represent fatigue strength for conventional materials as well as composites. The S-N curve for composites is typically a semi-log plot of constant amplitude cyclic stress versus cycles to failure for a given stress ratio (R). S-N data are obtained from fatigue testing of small test specimens representing specific design details.

It is known that fully reversed loading (R=-1) is the most severe fatigue loading for composite elements. The slopes of the S-N curves for tension-tension (R>0) and compression-compression (R<0) are smaller than for R=-1.

Defining the S-N equations of elements is an essential step of the process evaluation of fatigue strength of both metallic and composite airframe elements.

The review, analysis and compilation of some publications were obtained and submitted to analytical expressions for the S-N equations of typical airframe composite elements - see Table 1.

<table>
<thead>
<tr>
<th>Airframe Composite Element</th>
<th>The S-N Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin (unnotched laminate) without damages</td>
<td>$\sigma_a = c + m \lg N$</td>
</tr>
<tr>
<td>Skin (unnotched laminate) with impact surface damages</td>
<td>$\sigma_a = c + m \lg N$</td>
</tr>
<tr>
<td>Elements with open holes</td>
<td>$\sigma_a = c + m \lg N$</td>
</tr>
<tr>
<td>Elements with filled holes</td>
<td>$\sigma_a = c + m \lg N$</td>
</tr>
<tr>
<td>Shear bolted joints</td>
<td>$\sigma_{abr} = c + m \lg N$</td>
</tr>
<tr>
<td>Bonded joints</td>
<td>$\bar{q} = c + m \lg N$</td>
</tr>
</tbody>
</table>

The resulting equations can be used for engineering calculations of fatigue life on the stage of preliminary and detailed design of modern aircraft (to obtain experimental data of aircraft full-scale fatigue test).
NONLINEAR TRANSIENT ANALYSIS OF SANDWICH PLATES WITH PARABOLICALLY VARYING THICKNESS

S. Susler¹, H. S. Turkmen¹, and Z. Kazanci²

¹Istanbul Technical University, Faculty of Aeronautics and Astronautics, Istanbul, Turkey
²Turkish Air Force Academy, Aerospace Engineering Department, Istanbul, Turkey

The sandwich plates are important components of the engineering structures. They are particularly used to obtain light-weight structures. In this study, the dynamic behavior of simply supported laminated sandwich plates with parabolically varying thickness subjected to the air blast loading is investigated numerically. The theory is based on the classical sandwich plate theory including the large deformation effects, such as geometric non-linearities, in-plane stiffness and inertias, and shear deformation. The geometric nonlinearity effects are taken into account by using the von Kármán large deflection theory of thin plates. The nonlinear equations of motion for the sandwich plate are derived by the use of the virtual work principle as shown in Eq. 1.

\[
\begin{align*}
L_{11} u^0 + L_{12} v^0 + L_{13} w^0 + N_1 (w^0) + \bar{m} \ddot{u}^0 - q_x &= 0, \\
L_{22} u^0 + L_{23} v^0 + L_{23} w^0 + N_2 (w^0) + \bar{m} \ddot{v}^0 - q_y &= 0, \\
L_{33} u^0 + L_{32} v^0 + L_{33} w^0 + N_3 (u^0, v^0, w^0) + \bar{m} \ddot{w}^0 - q_z &= 0.
\end{align*}
\]

Here, \( L_{ij} \) and \( N_i \) denote linear and nonlinear operators, respectively; \( \bar{m} \) is the mass of unit area of the mid-plane, \( q_x, q_y \) and \( q_z \) are the load vectors in the axes directions. Approximate solution functions are assumed for the space domain and substituted into the equations of motion. The Galerkin method is used to obtain the nonlinear differential equations in the time domain. The finite difference method is applied to solve the system of coupled nonlinear equations. The displacement-time and strain-time histories are obtained.

The sandwich plate with parabolically varying thickness is also modeled using the finite element method. ANSYS finite element software is used for this purpose. The theoretical results are compared with ANSYS finite element results. It is shown that there is an agreement between the displacement-time and strain-time histories predicted using both methods. A parametric study is conducted considering the effect of thickness variation by using theoretical method and ANSYS. The effect of the ratio of face sheet thickness to the core thickness on the dynamic response is also investigated.
TAILORING OF COMPOSITES BY USING THERMO-HYGRO-MECHANICS (THM) (BROADENING THE POSSIBILITY BY GENERALIZING FROM TS -> TM -> THM)

A. Szekeres and B. Fekete
Dept. Applied Mechanics, TU Budapest, Budapest, Hungary

In case of tailoring of composite materials the increasing No. of parameters gives broader possibility [1, 2]. Taking into account the different coupled fields of mechanics and according to these the different material properties, several new parameters can be involved into the tailoring. The most important object coupling, when dealing with composites, is that of heat and moisture. On the other hand, the mode coupling of diffusion and convection is common case [3]. Applying these, the cross-coupled diffusivities, convectivities and coefficients of expansion appear. Taking into account the second sound phenomenon, the gain is doubled, i.e. higher accuracy and new parameters: the cross-coupled relaxation times.

Of course, the question of numerical values of the new parameters arises. We are going to show how to obtain them by theoretical and mainly by experimental considerations [4].

Let us analyse how to get the different coupled fields surfing from mechanics (M) to THM through thermal stresses (TS) and thermo-mechanics (TM) [5].

The notion TS includes much more than the meaning of the expression shows. Originally it gave answer on the problem of the displacements, strains, stresses and temperatures due to inhomogeneous temperature fields. Now-a-days it is hopeless to list all the topics included in TS, but no doubt, the name TM is the good one.

One aspect of the role of TM is the interdisciplinarity. The TM became the most typical coupled field of mechanics, maybe of the whole engineering science. It has double roots. The theoretical one is based on the material structure. From this point of view it is clear, that M and thermodynamics (TD) are generally and mutually coupled, i.e. no M without TD and vice versa. A very simple verification could be that both M and TD deal with motion and forces, but in different frames, i.e. macro and micro. The practical root is very clear, i.e. the overwhelming majority of the materials are not only deformable, but also thermoscopic.

Following this way, one soon reaches the problem of THM, because most of the modern engineering materials, e.g. composite, bio tissue, concrete, etc. are also hygroscopic. And dealing with such materials the practical problems need more and more theoretical basis, so we get back to the triple coupled fields of TM, i.e. to THM, or generally to the interdisciplinarity of THM.

The paper analyses the increasing No. of the parameters in tailoring and also the theoretical, numerical and experimental possibilities to obtain the material properties [6].

REFERENCES

STUDIES OF MANUFACTURING DEFECTS FOR COST-EFFECTIVE PERFORMANCE OF COMPOSITE STRUCTURES

R. Talreja

Department of Aerospace Engineering, Texas A&M University, College Station, Texas, USA
Polymer Engineering, Luleå University of Technology, Luleå, Sweden

Current applications of composite materials are in diverse fields ranging from land, sea and air transportation, to energy production and storage, and more. Except in some aerospace applications where defect threshold requirements are implemented, in most applications manufacturing defects must be tolerated in order to meet the cost requirements. It is imperative therefore to have a methodology for assessment of defects, in particular under long term loading such as fatigue. This paper will outline a design strategy for cost-effective composite structures and describe a field coined by the author as “defect damage mechanics”. A few problems in this field will be discussed with solutions to illustrate the methodology for assessment of cost-effective performance of composite structures.
INFLUENCE OF FIBERS ORIENTATION AND VOLUME CONTENT ON THE FRACTURE OF FIBER-REINFORCED CONCRETE

S. Tarasovs, E. Zīle, and V. Tamužs

Institute of Polymer Mechanics, University of Latvia, LV-1006, Riga, Latvia

Steel fiber reinforced concrete is potentially very promising material with unique properties, which currently is widely used in some applications, such as floors and concrete pavements. However, lack of robust and reliable models of fiber reinforced concrete fracture limits its application as structural material. In this work new numerical model is proposed for predicting the crack growth in fiber reinforced concrete.

Single fiber pull-out test is often used as a means to predict the fracture behavior of fiber reinforced concrete. Experimentally obtained pull-out properties of steel fibers are used to obtain averaged traction-separation law, which then are used in numerical models of concrete fracture. The averaged traction-separation law usually takes into account the volume fraction and random orientation of steel fibers in concrete, however this approach has some limitations. In real concrete structures the random orientation of fibers is disturbed near the external boundaries of the structure, the fibers distribution may be non-uniform, forming compact clusters with high volume content, the crack path is not straight. These effects are not taken into account in simple models.

In current work, new numerical model is proposed, which takes into account the exact position and orientation of each fiber. The model uses cohesive zone approach within the finite element framework to model the cracking of the concrete. The cohesive elements are embedded between all solid elements, in result the crack path is not pre-defined and the crack growth direction is chosen automatically to minimize the energy. The effect of reinforcing fibers is modeled using non-linear spring elements, connecting nodes of neighboring solid elements at the location of the fiber. The properties of the spring elements are defined using experimentally obtained pull-out characteristics of single fibers embedded in concrete matrix at different depth and angles. This model allows one to simulate the initiation and propagation of the crack, taking into account the non-uniform distribution of reinforcing fibers. In this work the effect of different fiber orientations and volume contents on the fracture propagation in fiber reinforced concrete specimens was studied.
MONITORING THE CURE OF EPOXY RESINS WITH DIFFERENT METHODS

G. Teteris, U. Braun, and W. Stark

Federal Institute for Materials Research and Testing, Unter der Eichen 87, 12205 Berlin, Germany

The monitoring of the monomer/oligomer curing kinetics and degree of conversion is of great interest for epoxy industry, especially for quality control of prepreg producers.

The curing process was studied on different commercial, room and high temperature curing epoxy resin compounds using four measuring methods:

1. differential scanning Calorimetry (DSC),
2. infrared spectroscopy,
3. rheology with a plate–plate geometry by oscillation and
4. ultrasonic measurements.

The objective of the study was to compare the effectiveness and sensitivity of these methods and the correlation of the results of the methods with each other.

With the DSC the curing process was investigated at temperature sweep with different heating rates and by isothermal plateaus at different temperatures and equal isothermal condition time. The difference of the curing grade after these isothermal steps was detected by a second heating step with temperature sweep at constant heating rate. Shift of glass transition temperature to higher values and decreasing exothermal peak of reaction were obtained with increasing isothermal curing temperature. The results are also showing that the sensitivity of this method decreases at final stages of curing.

With infrared spectroscopy the dynamic of the curing process can be observed by changes of different specific chemical bonds such as decrease of the absorption bands of the oxirane ring. For the high temperature resin the experiments were carried out at the same isothermal conditions as by DSC. The sensitivity of this spectroscopic method is quite the same as for the other methods.

From the results of rheological experiments it was found that the dynamical viscosity and both loss and storage modulus are increasing with curing degree. At early curing stages the loss modulus shows the highest sensitivity from rheological parameters for the curing process start. The viscosimetric method also looses on sharpness at higher degrees of conversion like DSC.

For ultrasonic investigations a temperature-controlled mould with two incorporated sensors was used. The measuring frequency was 4 MHz. Measuring the pulse travel time and amplitude of the ultrasonic pulse the change in sound velocity and damping during curing process are registered.

All methods are compared and the advantages and disadvantages explored. Their practical usability for composite and prepreg characterisation will be discussed on examples of practical industrial applications. Our experimental data demonstrate that the obtained results give comparable results of curing kinetics and curing grades and ultrasonic process control can be successfully integrated in industrial processes.
EFFECT OF SMALL CONCENTRATIONS OF MULTIWALL CARBON NANOTUBES ON MECHANICAL AND TERMOPHYSICAL PROPERTIES OF EPOXY NANOCOMPOSITE

K. Timchenko¹, A. Bondon², T. Glaskova¹, and A. Borisova¹

¹Institute of Polymer Mechanics, University of Latvia, Riga, LV-1006, Latvia
²Ecole Nationale Supérieure des Ingénieurs en Arts Chimiques Et Technologiques, Toulouse, Cedex 04, France

Carbon nanotubes (CNTs) have some unique mechanical properties and their application for polymer composites may be rather effective. At present CNT application in polymer composites is not active and needs more scientific research.

The aim of the current work is to determine the basic regularities of mechanical and thermophysical properties of epoxy resin composite filled with various contents of multiwall CNTs.

Epoxy resin Araldite LY 564 and hardener XB 3486 (Huntsmann) as well as Epocyl 1040 (Nanocyl) which was a master batch with multiwall CNT prepared on its basis were used for the work.

The nanocomposite (NC) specimens were prepared by intensive manual mixing for 5 min at room temperature of the resin with masterbatch in the proportion required for the desired content of CNTs in particular series. NC specimens were cured for 16 hours at 60 °C.

Samples series of pure resin and 16 NC series with CNT content 0.0005, 0.0011, 0.0022, 0.0065, 0.011, 0.012, 0.027, 0.05, 0.11, 0.27, 0.43, 0.54, 0.65, 1.1, 1.6 and 2.2 wt. % were prepared. Quasistatic tensile tests were performed at ZWICK 2.5kN testing machine at crosshead rate 5 mm/min. The density of NC specimens was measured by hydrostatic weighing in ethylene. Thermophysical measurements were performed by HotDisc TS500 device using cylindrical NC specimens.

According to the results of mechanical tests, an increase of strength up to 14% and the maximum strain up to 62% were established at CNT content of 0.0022%. Further increase of CNT content caused slight decrease of these characteristics. Tensile elastic modulus of NC didn’t change significantly with the increase of CNT content in the NC.

According to the results of thermal testing a gradual increase of the thermal conductivity up to 17% was established with the increase of CNT content in the NC. The results of density measurements correlate rather well with the mixture law.

On the basis of these experiments, it can be concluded that clusters of nanoparticles may be present in the NC at high contents of CNTs which weakens the NC structure. CNT clusters both may be present in the original master batch and appear in the NC during curing process.
Cracking and tension-stiffening probably have the most significant effect on results of numerical modeling of flexural concrete elements subjected to short-term loading. The tension-stiffening effects usually need to be included in such analysis.

Present study experimentally and theoretically investigates tension-stiffening in concrete beams with composite reinforcement. It is based on test results obtained by the authors and uses the innovative technique for tension-stiffening analysis [1]. The test program consisted of four beams (having 3 m span): (1) concrete beam reinforced with Schöck ComBAR glass fibre reinforced polymer (GFRP) bars; (2) steel fibre reinforced concrete (SFRC) beam reinforced with the GFRP bars; (3) SFRC beam reinforced with steel bars and (4) concrete beam reinforced with steel bars. All the beams had the same bar reinforcement ratio (0.6%). Volume content of the fibres in the concrete mix was 1.0%.

The beams were tested under a four-point bending scheme. Prior to the tests, measurements of concrete shrinkage were performed. Using the technique [1], free-of-shrinkage moment-curvature and average stress-average strain tension-stiffening diagrams, shown in Fig. 1, were derived from the test data. It can be observed that the tension-stiffening obtained in the beams reinforced with GFRP and steel bars is equivalent. As tension-stiffening is closely related to bond characteristics of reinforcing bars, similar conclusion can be made in regard to bond quality of GFRP bars. The effectiveness of the steel fibres regarding the tension-stiffening effect can be also pointed out.

![Moment-curvature and average stress-average strain tension-stiffening diagrams.](image)

REFERENCES

EFFECT OF IONIZING RADIATION ON THE THERMAL CONDUCTIVITY OF LAMINATE

K. B. Tlebaev and A. I. Kupchishin

Abai Kazakh National Pedagogical University, Republic of Kazakhstan

In the present analysis of radiation effects in composite materials is difficult at the present level of understanding of the mechanism of physical and mechanical processes occurring in the composite material under the action of ionizing radiation.

The cause of difficulties is the complexity of the structure of composites, in most cases, the lack of information about the properties of individual components and of radiation effects in them, non-additives properties of the system.

Moreover, there is no practically studies related to the almost complete absence of work on the effect of radiation on physical and mechanical properties of composites.

In this paper a laminate consisting of two or more layers of organic fillers is investigated. The data are presented on the effect of irradiation and temperature on the thermal conductivity of laminate mark “LG”.

Analysis of the temperature and dose dependencies of thermal conductivity of the laminate has shown that the thermal conductivity in the temperature 80-330 K, as well unirradiated and irradiated laminate increases linearly with increasing temperature. Irradiation of the laminate reduces the thermal conductivity.
ADHESION MECHANICS
(Adhesion joints and discrete models of composites. Contact layer method)

R. A. Turusov and L. I. Manevich

Semenov Institute of Chemical Physics, Russian AS, 4 Kosygina St., Moscow, 119991, Russia

Wide application of composites and adhesion joints requires the development of specific branch of deformable solid body mechanics — adhesion mechanics, the speciality of which consists of accounting for the surface interactions on the boundary of two media. In regards to the composite materials, one may speak of the micromechanics of the composites, which, in this case, relate homogeneous (on average) materials to macromechanics. Unlike macromechanics, in which the analysis of the behavior of solid bodies begins with the investigation of the simple case of the arising of the homogeneous stress state, particularly during the experimental definition of the mechanical properties of the material, micromechanics always deals with the nonhomogeneous stress state and inhomogeneity can be strongly expressed. This characteristic defines the complicated nature of adhesion mechanics problems, which is the main reason for the significant lag in the theory behind widely conducted (in connection with practical demands) experimental investigations.

So the first main problem of adhesion mechanics is the determination of nonhomogeneous stress state and the requirement of true strength evaluation of the adhesion bond of the adhesive-substrate pair given, that does not depend on the geometry of the sample. Speaking of adhesion joints we mean glued joints and discrete models of composites.

The second main problem is the characterization of the contacts in an adhesion joints, which is closely connected with the first problem. The experience of adhesion investigations led the authors to the formation of a hypothesis regarding the influence of the density and bond energy on the contact boundary on the stress–strain state of not only the boundary, but also the contact bodies themselves.

The third problem is the calculation of the residual (technological) stresses and their influence on the mechanical behavior of adhesion joints.

The fourth problem is the selection of the criteria and true strength evaluation of the models of adhesion joints and discrete models of composites.

The fifth problem is the elastic and relaxation behavior of the adhesive material in the state of thin interlayer between substrates with high Young modulus.

In present work, a solution of the above-mentioned problems by solving a series of basic problems of stress state of different models of adhesive joints mainly with the help of the contact layer method is given. This method allows to acquire the problem solution mainly in closed species and to apply physically clear criteria of strength. It gives an opportunity to satisfy all the main boundary conditions precisely and is specified by absence of singular behavior in angular points (in contrast to the precise solution according to elastic theory). A new methodology for the evaluation of the contact layer parameters, a methodology for comparison of this theory and the experiment, and a methodology for true strength evaluation of the adhesive bond has been elaborated. It is commonly known that in the above-mentioned experiment only the average (integral) adhesion strength can be measured. The influence of thickness and stiffness of the interlayer material and the particle size of the stiff filling material, including nano-sizes, on the Young modulus of the composite has been investigated by theory and experiment. The effect of synergetic increase of the Young modulus of relatively thin and soft adhesive interlayer has been elucidated by theory and experiment.
Highly stressed bladed rotors are used in turbomachinery. With this work, we concentrate on impellers for turbo molecular pumps [1]. Increasing the efficiency of these machines leads to energy savings and an increased performance. This can be done either geometrically by optimization of the flow behavior or by increasing the impellers rotational frequencies, which increases the pumping speed linearly. The latter is focused on the structural strength of the construction and the material used. Using conventional light alloys an increase of speed is difficult to achieve, although improvements are possible by optimizing the mass distribution e.g. producing very thin blades.

As a new approach a rotor with 17 blades in bladed disk construction (Fig. 1) made of carbon fiber reinforced plastics (CFRP) with a 35 % higher operational speed compared to a state of the art bladed rotor made of high strength aluminum alloy was developed. To get the full benefit of the orthotropic properties of CFRP the rotational symmetry must be reflected in the fiber layout, which demands either radial or tangential fiber orientation. Therefore, the Tailored Fiber Placement (TFP) technology was used, which allows a high flexibility for the fiber layout [2]. For consolidation resin infiltration was performed using a modified vacuum assisted process and the final geometry was generated using a five axis milling machine. To achieve a constant thickness of the rotor, the tangential fiber layer has to compensate the radius dependent thickness of the radial orientated fibers. However, a compromise had to be found as the stress distribution demands a strong tangential layer near the rotational axis as well as a strong radial layer within the blades.

For finding the optimal layer thickness distribution also considering TFP manufacturing restrictions was determined using an adapted finite element analysis (FEA) model. Additionally, a numerical modal analysis and a numerical failure analysis were performed. Finally, the theoretical results were verified on manufactured rotors by experimental modal analysis and burst tests.

REFERENCES
REFRACTORY OXIDE POWDERS AND CERAMIC COMPOSITES BASED ON THEM

T. M. Ulyanova\textsuperscript{1}, L. V. Titova\textsuperscript{1}, N. P. Krutko\textsuperscript{1}, A. A. Shevchonok\textsuperscript{2}, and A. R. Luchenok\textsuperscript{2}

\textsuperscript{1}Institute of General and Inorganic Chemistry of NAS of Belarus, 9/1 Surganov St., Minsk, 220072, Belarus, ulya@igic.bas-net.by

\textsuperscript{2}Institute of Powder Metallurgy of NAS of Belarus, 41, Platonov St., Minsk, 220005, Belarus

Nanomaterials on the base of refractory compounds have been intensively investigated recently in connection with the development of nanotechnology. The creation of the ZrO\textsubscript{2} based materials with important operation characteristics is based on the alloying of zirconia by oxides of alkaline earth or rare earth metals which permits to get high temperature ZrO\textsubscript{2} tetragonal or cubic form at relatively low temperatures. The compounds on its base are used to get both: structural (blades of turbines, cutting tool) materials as well as functional ones (solid body power supply, medical products, targets for emitters). The proportion between tetragonal and monoclinic phases of zirconia, which can be changed depending not only upon the quantity of incorporated additive, but also upon temperature or bar impact on the material, has a considerable significance in determining the properties of this ceramics. In connection with the aforesaid, to investigate consolidation processes for nanostructured powders including their moulding, solid phase reactions at the phase boundary and structure conversions in heat processing, which determine physical and mechanical properties for the ceramics, is an important task.

In the present work, the influences of thermal-baric effect in the process of nanostructured alumina and zirconia powders consolidation on structure and physical-mechanical properties of the composite ceramics have been investigated. The samples of ceramics have been prepared from nanostructured powders (ZrO\textsubscript{2} +3 mol. \% Y\textsubscript{2}O\textsubscript{3}) and Al\textsubscript{2}O\textsubscript{3} in ratio from 100 : 0 to 0 : 100 wt.% in two ways: by static uniaxial pressing and by pulse pressing. Then part blanks were annealed in the temperature region 1560–1670\textdegree C. During pulse process a crystal structure of samples was disordered, and monoclinic ZrO\textsubscript{2} lattice was partially deformed. After a heat treatment of a blank the crystal structure of metal oxides was restored. Ceramics of oxide powders with content 100 - 50 wt.\% PSZ synthesized at the 1100\textdegree C possessed more higher level of properties than one of active powders prepared at the 900\textdegree C.

The fulfilled investigation permitted to establish the next: substance amorphization, partial deformation and disordering for crystal oxides lattice occur during the moulding of blanks from nanopowders by explosion method, the crystal lattice is restored in further heat treatment. To get dense ceramics from composition powders having compositions from 100 up to 50 wt. \% PSZ, it is advisable to use powders with annealing temperature higher than 1000 \textdegree C. Annealing temperature of powders, enriched with aluminium oxide, must not exceed 900 \textdegree C. In general, to get small one type parts from nanostructured powders of refractory oxides, one can use one axial static pressing method. To get large blanks, it is expedient to use impulse moulding method with further single annealing at a given temperature. Prepared ceramic samples stand more than 100 shocks from 900 to 10\textdegree C (water). During boiling in acid and alkali medium ceramic samples loss 0.5–1 wt.\%.

Porous as well as high density ceramics with high engineering characteristics can be obtained from nanostructured powders of refractory ZrO\textsubscript{2}-Y\textsubscript{2}O\textsubscript{3}-Al\textsubscript{2}O\textsubscript{3} oxides in observing definite technology conditions.
RESEARCH INTO THE MICROMECHANICS OF THE PLASTIC-ELASTIC BEHAVIOUR OF ANISOTROPIC COMPOSITE MATERIALS UNDER STATIC LOADING BY THE ACOUSTIC EMISSION METHOD

A. Urbach¹, M. Banov¹, V. Turko², K. Savkov¹, Y. Feshchuk¹, and K. Carjova¹

¹Riga Technical University, LV-1658, Riga, Latvia
²“Aviatest LNK” Ltd

The main topic described in this paper is based on the results of the research about unidirectional composite materials failure under static tension load as well as includes an attempt to evaluate the nature of such failure by using the acoustic emission (AE) method.

During the research the square plates were used as samples of composite materials. One part of the samples was stressed in longitudinal direction of fibres; another part was stressed in transverse direction of fibre. During the experiment with samples where stress was directed longitudinally fibres, some samples were exposed to three-fold or sixfold load up to 20-40% of the breaking load. At the same time the simultaneous recording of total AE and the deformation of samples on the basis of strength measurement data were carried out.

For the samples, which were stressed transversely fibres, AE method had shown that the moment of failure initiation in the internal structure of samples was recorded by 5-6% earlier than the strength measurement showed (Fig. 1). In conclusion the samples exposed to overload, both the AE method and the strength measurement showed that in this case the failure begins almost 10% earlier.

![Fig. 1. Dependence of AE and deformation on the sample loaded across the grain.](image)

For the samples, which were stressed longitudinally fibres, the diagram of their deformation (dependence of deformation on the load) had shown a linear dependence in the whole load area right up to the sample failure.

However, the analysis of AE signals accumulation showed that the accumulation of AE signals has a S shape, which implies a three-stage micromechanical process of the internal failure of a sample. For the samples without aging: stage 1 is intensive growth of total AE at the initial moment with deceleration, stage 2 (a longer one) is stabilization of total AE growth velocity, stage 3 (approximately 10% before the failure) is acceleration of intensive growth.

The main conclusions:
- Three-fold or sixfold aging under small values of load (up to 20% of the breaking load) has a small influence on the behaviour of AE signals accumulation curve.
- Three-fold aging under large values of load (up to 40% of the breaking load) has a considerable influence on the behaviour of AE accumulation curve; however, in both the first and the second cases, aging does not exert any influence on the ultimate strength under the given load conditions.
RESEARCH ON THE SERVICE PROPERTIES OF INTERMETALLIC COATINGS FOR THE BLADES OF AERO-ENGINE TURBINES ON THE BASIS OF TITANIUM-ALUMINIUM

A. Urbach, K. Savkov, M. Urbaha, and G. Rijkuris
Riga Technical University, LV-1658, Riga, Latvia

The modern aero-engine is an extremely stressed assembly that forms the structure of aerial vehicles. It is exposed to both physical and thermal loads. The struggle for economic and traction efficiency makes the designers of gas turbine engines (GTE) constantly look for the ways of increasing the compression ratio of compressors and the temperature of gases in front of turbines.

By use of the Laboratory of Vacuum Technologies of the Institute of Transport Vehicle Technologies of the Riga Technical University authors have accumulated extensive experience in creating coatings for different purposes (wear, heat resistant, decorative coatings etc.) by various technologies including diffusion saturation, vacuum ion-plasma sputtering, ion bombardment and other technologies.

During this research authors have created new intermetallic alloys for the blades of aero-engine turbines on titanium-aluminium basis with the density of 3.9-4.2 g/cm³ containing 44-65% of titanium and 35-56% of aluminium as well as other alloying elements in the range from 0.1 to 10%. Also the method of sputtering an intermetallic titanium-aluminium coating was developed and pilot samples were obtained by using an experimental facility with separate sputtering of titanium by an arc source and aluminium by a magnetron source using specific experimental vacuum chamber.

The thickness of the created coating was about 10 − 15 µm, which is 2 – 3% of the total thickness of the working part of the blades of aero-engine turbines. This slight change in the geometry of the profile of the blades should not lead to a change in the aerodynamic characteristics of the engine.

The paper includes results of the research on oxidation process observed on the surface of coated samples within the high-temperature range (500 – 825ºС) carried out with the use of a scanning electronic microscope (see Fig.1). The basic peculiarities of the process of coatings destruction under high-temperature oxidation conditions were determined – the created alloys have high heat resistance within the range of 700–1000ºС and can be also used as a material for heat resistant coatings intended for products made of titanium alloys.

Fig. 1. General view (left) and microstructure (right) of sample surface after the test (temperature 825ºС).
EXPERIMENTAL EVALUATION OF THE HARDNESS AND ELASTIC PROPERTIES OF WEAR-RESISTANT NANOSTRUCTURAL ION-PLASMA COATINGS BY NANOINDENTATION

M. Urbaha, A. Urbahs, and K. Savkovs
Riga Technical University, LV-1658, Riga, Latvia
e-mail: margarita.urbaha@gmail.com

The analysis of different methods of increasing wear resistance shows that the most perspective method is related to the improvement of part surface properties by creating special protective coatings [2]. Innovative nanostructured coatings (KJONBOMU), which are created on the basis of ion-plasma sputtering technologies, differ by technological effectiveness and a wide range of physico-mechanical and service properties.

The characteristics obtained during nano-indentation are used for the evaluation of wear resistance of ion-plasma coatings. During nano-indentation, one of the basic characteristics of material is the relation of its hardness $H$ to the modulus of elasticity $E$ – $H/E$. Another quantitative comparative characteristic of resistance to plastic deformation is relation $H/E_r^2$ where is $E_r$ a modified modulus of elasticity in the contact “indenter – product coating”.

The results of nano-indentation on the example of the two-layer coating of one of the plungers are presented in Fig. 1.

![Fig. 1. The results of nano-indentation of the plunger coating KJONBOMU: 1 – time curve of indentation depth $h$; 2 – time curve of normal force $P$.](image)

For the plungers with coatings created by the combined method (KJONBOMU), the values of hardness were 37… 41 GPa with modulus of elasticity 440…475 GPa. The average value of the relation $H/E$ was 0.085, while $H/E_r^2$ was – 0.283 GPa. The range of received values of parameters $H/E$ and $H/E_r^2$ confirms the presence of nanostructure of the coating and is an indicative of its high wear resistance and ability to resist plastic deformation [1].

REFERENCES

INFLUENCE OF THE SURFACE FINISH QUALITY OF REINFORCEMENT ON THE RESISTANCE OF COMPOSITES TO OPERATIONAL FACTORS

A. E. Ushakov, Y. G. Klenin, T. G. Sorina, T. V. Penskaya, and A. V. Sokolova

“Aptech-Dubna”, Russia,
e-mail: mail@apatech.ru

Research has been conducted to investigate influence of operational factors such as temperature and moistening on performance of infusion composites made of vinylester, polyester and PEU resins and glassfiber fabrics of similar composition and structure from two different manufacturers and to estimate the received results.

Two multiaxial QI E-glass reinforcements with the same properties supplied by different companies have been selected. Simultaneously fiber reinforced plastics of similar composition and structure based on the selected reinforcements have been manufactured.

Properties of composites have been investigated at standard and elevated temperatures in the initial state and after holding in conditions simulating influence of climatic factors (elevated temperature and moistening) under two types of deformation (compression and tension of single-bolted double-shear joint).

During testing of composites in the initial state a slight advantage of one type of reinforcement has been observed which provided for a higher level of mechanical properties of composite materials.

The comparison of impact of artificial ageing of material (impact of moisture in form of vapor or water) on degradation of its properties has been made.

As a result of comparison of the test results for composite materials based on two types of reinforcements of similar composition and structure a significant difference in their behaviour has been observed after impact of operational factors due to surface finish quality of the reinforcement (type of sizing or nonuniform sizing application). Thus, strength index of one reinforcement almost didn’t change and strength index of the other one decreased by 2.5 – 3 times.

Microstructure analysis of fracture of the composite specimen has been carried out to estimate surface condition of the reinforcement and its relation to polymer matrix after thermal-moisture impact.

Fig. 1. Micrograph of fracture of the reinforcement No. 1 based specimen.

Fig. 2. Micrograph of fracture of the reinforcement No. 2 based specimen.
INFLUENCE OF CARBON NANOTUBES (CNTs) AND METAL SALTS IN THE NANOFORM ON THE STRUCTURE OF A POLYMER MATRIX AND ON THE PROPERTIES OF POLYMER MATRIX-BASED COMPOSITES

A. E. Ushakov, Y. G. Klenin, T. G. Sorina, T. V. Penskaya, and K. G. Kravchenko

“STTC Apatech-Dubna”, Russia, mail@apatech.ru

Research has been conducted to develop resins for polymer composite materials (PCM) and adhesives modified with carbon nanotubes and metal salts.

It proved to be effective to modify resin “ApATeCh KPR-150” by introducing nanobarites which resulted in increase of physical-mechanical properties of the composite based on this type of resin. Introduction of not less than 1% of nanobarite into the matrix leads to increase of all investigated elastic-strength properties of PCM, in particular: ultimate shear strength – by 22.7 %, ultimate compression strength by 17.2 % and crack resistance during compression by 15.6 %.

As a result of nanobarite influence, a new structure in the polymer matrix is developed in the form of cylinder-shaped “sprouts” (Fig. 1) which apparently had an impact on increase of mechanical properties of PCM which depend on properties of a polymer matrix: shear strength, compression strength and crack resistance during compression.

During experiments it has been confirmed that resins with nanoadditives are very reasonable and convenient to use, their required concentration can be reached by means of dilution with the base resin and with simultaneous mechanical mixing and thus stable suspensions with the specified content of nanocomponents can be received.

A positive result can be obtained when CNTs are introduced into an epoxy composition “Sikadur 330” (Fig. 2), which resulted in increase of failure strain of adhesive joint by 34 % during uniform shear test of the PCM adhesive joints with each other, and this facilitated a 16% increase of longitudinal strength of the adhesive joint.

Two nanoforms have been compared: TiO₂ and nanobarite in terms of their impact on properties of “ApATeCh KPR-150” based composite and it has been revealed that chemical nature of a nanocomponent has influence on properties of the polymer matrix and composite material.

Fig. 1. Matrix «АпАТэК КПР-150» modified with nanobarite.

Fig. 2. Adhesive “Sikadur 330” modified with CNT.
THE MODELING OF CREEP FOR POLYMER-BASED NANOCOMPOSITES
BY USING AN ALTERNATIVE NONLINEAR OPTIMIZATION APPROACH

I. Viktorova¹, B. Dandurand¹, S. Alexeeva², and M. Fronya²

¹Department of Mathematical Sciences, Clemson University, Clemson, SC 29634, USA
²Institute of Machines Science of RAS, 4 Malyi Kharitonievsky By-Street, Moscow, 101990, Russia

The presented approach is based on the nonlinear hereditary type relationship between stresses, strains and time in viscoelastic solids - materials with memory. It can be modeled by the second type of Volterra's equation (known as Rabotnov’s model).

It has been shown that such an equation can describe rather successfully the wide range of materials including polymers, composites and nanocomposites.

Three types of polymer based materials with different modifications of carbon nanofillers were tested in experimental program on creep at various loading level and on quasistatic loading. The analysis of substantially different creep behavior was accompanied by the structural analysis including the microscopic scanning and nanoindentation testing.

The experimental data is modeled by the governing equation, described as Rabotnov's model. The choice of kernel for the integral operator is the subject of several objective considerations. The exponential of arbitrary order Rabotnov's function presents the most general type to satisfy the constraining conditions.

With the use of the Rabotnov's kernel comes the need to obtain material-dependent parameters associated with the kernel. The standard application of the least squares approach for obtaining optimal parameter estimates given experimental observations is difficult due to expensive and error-prone function evaluations arising from the use of the Rabotnov's kernel.

This work presents a means to obtain an alternative formulation of the least squares approach with the use of the Laplace-Carson transform that yields good parameter estimates with the use of function evaluations that are inexpensive and reliable. Validity and robustness of obtained parameter estimates are also discussed.

It is shown that the problem of obtaining optimal parameter estimates is ill-conditioned. There will not be a unique set of optimal parameters for a given material. Instead, optimal regions in the parameter space are detailed.
INFLUENCE OF SELECTED PARAMETERS OF DRAWING PROCESS ON THE
EXPANSIVE DEPOSITION OF THE INNER PE LINING IN PIPELINES

G. Wróbel¹, M. Szymiczek², and M. Rojek³

Faculty of Mechanical Engineering, Department of Processing of Metals and Polymers, Konarskiego
St. 18A, 44-100 Gliwice, Poland

e-mail: ¹gabriel.wrobel@polsl.pl,²malgorzata.szymiczek@polsl.pl,³maciej.rojek@polsl.pl

This paper describe the free drawing process of PE pipes in the aspect of time characteristics of the viscoelastic return. This viscoelastic return is conditioned by parameters free drawing process - diameter reduction degree, drawing die angle, temperature, introductory pipe diameter, and introductory pipe wall thickness. Obtained dependencies were assumed to be the basis for formulation of conclusions as to the choice of essential process conditions for the technological sequence of PE lining deposition in the outer coating of installation pipes or reconstruction of a transmission channel. The final effect presentation is worked out methodology used in identification of physical parameters of a PE pipe drawing model as the main phase of a viscoelastic deposition of lining in two-layer pipes. Particular attention was focused on the need to take into consideration changing friction conditions in the drawing die area and to determine the value of the friction factor.
PROPERTIES OF RIGID POLYURETHANE FOAMS FILLED WITH GLASS MICROSPHERES

V. Yakushin, L. Belkova, and I. Sevastyanova

Latvian State Institute of Wood Chemistry, Dzerbenes 27, LV-1006, Riga, Latvia
e-mail: yakushin@edi.lv

Hollow glass microspheres are successfully used for plastic foam filling. The main research in this area has been done for foams with middle and high density [1, 2]. Properties of rigid polyurethane foam with low density were investigated in this work.

The glass microspheres 3M Scotchlite™ of lowest density 0.125 g/cm³ (type K1) with the mean range of particle size 65 (15–125) µm were used as the filler of rigid polyurethane foam that was prepared using polyisocyanate Voratec SD 100 of Dow Chemical, mixture of polyether and polyester polyols of Elastogran Group and foaming agent Solkane 365/227.

Filled foams samples were prepared by hand mixing method. Prior to those glass microspheres were loaded in the polyol part of urethane composition. Series of neat and filled foam blocks with different density (from 54 to 90 kg/m³) were manufactured with glass microspheres content varying from 0.5 to 5 wt. % (4.6–34 vol. %). Properties of filled foams were compared with properties of neat foam of the same density.

Dependences of basic mechanical characteristics of polyurethane foams in tension (ISO 1926:2009) and compression (ISO 844:2007), as well as of thermal expansion coefficient, depending on the content of glass microspheres and foam density were obtained. An influence of the foam density and the content of microspheres on the geometric characteristics of the foam cellular structure and distribution of microspheres in the foam cellular carcass were investigated. The volume content of open and closed cells was also controlled with Gas Pycnometer AccuPyc 1340 (Micrometrics Instrument Corporation).

It was established that filled foam with density of 90 kg/m³ had compressive strength and modulus of elasticity in parallel (foam rise) direction 10–13 % higher than these for neat foam. Modulus of elasticity of filled foam in tension and compression in the transverse direction was higher than modulus of elasticity of neat foam of about the same extent. Tensile strength of the filled foam in transverse direction was slightly higher than tensile strength of the neat foam, if the content of microspheres did not exceed 3 wt. %. When density of foam decreased, the mentioned effect was noticed in less degree.

Data obtained by SEM (Vega Tescan 5136MM) were shown that longitudinal and transverse dimensions of the foam cells were decreased at the microspheres content increasing. At low filler content (0.5-2.0 wt. %), the glass microspheres were comparatively equally distributed in cells’ nodes and struts as separated particles. At higher filler content the equal distribution was disturbed and local agglomerates of microspheres were observed.

REFERENCES


COUPLED QUASI-HOMOGENEOUS ANISOTROPIC LAMINATES

C. B. York

School of Engineering, University of Glasgow, Glasgow, Scotland, G12 8QQ
Christopher.York@ gla.ac.uk

This article is the second in a series in which composite laminates are derived for standard angle- and cross-ply configurations with quasi-homogeneous orthotropic properties. In the previously article the uncoupled in-plane and out-of-plane stiffness properties were concomitant; thus simplifying the design of laminate configurations possessing other highly complex physical coupling responses, collectively referred to as bending-extension coupling. This article considers quasi-homogeneous anisotropic properties, where the in-plane and out-of-plane stiffness properties are both coupled and concomitant, i.e. special subsets of laminates identified from the general classes shown in Fig. 1, whereby bending stiffness is related directly to extensional stiffness:

\[ A_{ij} = D_{ij}H^2/12 \]  

and \( H \) is the laminate thickness.

These special laminate subsets, which represent a significant simplification for the purposes of laminate design, can be described as a Quasi-Homogeneous Anisotropic Laminates, or QHALs, providing identical anisotropy with respect to both extension and bending, thus providing maximum (and minimum) in-plane and out-of-plane reinforcement in the same direction. QHAL configurations therefore represent an important datum set from which to explore the complicating effects of coupled laminates.

Dimensionless parameters, including lamination parameters for laminate optimization, are also developed from which the elements of the extensional, coupling and bending stiffness matrices are readily calculated for any fibre/resin properties.

REFERENCES

COMPARATIVE ANALYSIS OF THE ENTIRE MANUFACTURE PROCESS OF COMPOSITE FILLERS FOR SANDWICH PANELS

A. Zaharov

OJSC “Perm Factory “Mashinostroitel”, Perm, Russia

Multilayer three-dimensional panel constructions (sandwich panels) of different materials and different forms strongly occupied a niche in various areas of production, such as aerospace, shipbuilding, architecture, construction, furniture, etc.

Wide design varieties of sandwich panels with various forms, materials and inner fillers, causes various options for technological processes, equipment and tools to make them.

Main internal filler structures of sandwich panels include placeholders in form of honeycomb, convolute, tubes, profiles of various shapes, etc.

Sandwich panels with honeycomb filler are fairly common today and technology of their manufacture is well known and tested. Technological processes and equipment for internal filler manufacture in form of cells, folds and convolute, that made from whole-leaf material, are at the stage of the single and pilot production. Usage of plastic forming operations without destroying integrity of material is the main feature of this type of fillers production. Use of whole-leaf internal filler material simplifies process of its manufacture, eliminates glue usage, as well as enhances performance of sandwich panels.

This article reviews designs and manufacturing processes options for sandwich panels fillers made of composite materials, and also researches of their mechanical properties.

We consider processes of polymer composite materials manufacturing with different types of fillings: honeycomb, corrugated. There is description of production processes, equipment, and their technological features. Finally, there is data on mechanical testing of different design options for fillers and their comparative analysis. These researches allow performing studies on influence of application design, manufacturing, material properties for the mechanical and deformation properties of filler.
Flexible graphite (i.e. FG) is a unique nanostructured composite material with temperature-independent high thermo-chemical durability, low coefficient of friction and high elastic properties. FG seals are easily breaking-in without erosive affection on the contact metal surfaces, fit for multifunctional usage in high-corrosive and high-reactive gas and fluid media. FG o-ring seals and their packs have high reliability, they do not require additional hermetization during long-term usage and work at temperatures up to 560 °C with pressures up to 40,0 MPa. Currently o-ring seals are greatly used in aerospace, metallurgical, oil-and-gas and chemical plants, power industry facilities, housing and communal service companies. Traditional full scale in-situ experiments with structures and prototypes for the development and optimization of seals are unreasonable due to a high risk of accidents with serious environmental and economic damage. Therefore, modelling makes it possible to predict thermophysical and mechanical properties of FG, describe mechanical behaviour and optimum design of o-ring seals and their packs corresponding to survivability and safety usage.

A thermomechanic model for initial operation mode description of large-scale production seals (intended for plunger seal in the stop valves) is developed with the account of a cylindrical nature of anisotropy type, obtained experimental data for elastic, friction, strength and thermophysical characteristics of FG. It was supposed that o-ring seal is a thick-walled, limiting homogeneous transversally-isotropic cylinder fixed in a an oil-seal housing by sealing bush (i.e. in all points of an external surface radial, hoop and axial displacements are dropped out). On one of the face surfaces pressure for hermetization has been set from a sealing bush, and on the other surfaces — work pressure. Axial displacements that modelled rod reciprocation in burn-in regimes in the direction of a closing ring and in the opposite side have been set on the internal lateral surface. The quasistationary mode of o-ring seal behaviour assumed absence of FG entrainment which was modelled by the set of the friction law for contact surfaces in the form of proportionality between radial and shear stresses. With consideration of given conditions analytical solutions for boundary-value problems have been received and stresses, strains and displacements have been defined.

The influence of thermoforce loading conditions on the character of stress-strain distributions along cross-sections of FG o-ring seals and their packs has been investigated by the use of numerical FEM solutions of 3D stationary boundary-value problems. Calculations have been made of estimation of damage mechanisms (damage from tension or compression in radial, hoop and axial directions, and from transversal and antiplane shear) affection on initial strength, of a comparison of different loading modes (reciprocating motion in sealing bush or opposite direction, and torsion of the plunger), height and conditions on contact surfaces (i.e. ideal contact, friction or slip) between seals on the maximum values of radial, hoop, axial, and shear stresses. The locations of damaged domains obtained from computational experiments correspond with the results of o-ring seals experience. That allows us to define an optimum hermetization pressure, justify recommendations to modify existing structures of o-ring seal packs and develop engineering techniques for refined strength analysis.

The authors acknowledge the support of the Russian Foundation for Basic Research (Grant RFBR–Urals No 11–01–96033).
PROBABILISTIC METHODS FOR THE ANALYSIS OF RANDOM STRUCTURES,
STRESS AND STRAIN FIELDS IN 2D AND 3D MATRIX-INCLUSION
COMPOSITES, HIGH-POROUS METALLIC FOAMS AND BONES

A. V. Zaitsev, A. V. Kislitsyn, V. S. Koksharov, Ya. K. Pokataev, and Yu. V. Sokolkin

Mechanics for Composite Materials and Structures Dept., Perm National Research Polytechnic
University, Perm, Russia

Prediction of the effective deformation properties and definition of the statistical characteristics of random structures, stress and strain fields at components of fibre- (2D) and particle-reinforced (3D) matrix-inclusion composites and high-porous biomaterials, bones and metallic foams are connected to finding the solutions of stochastically nonlinear boundary-value problems using various hypotheses on character of collective multiparticle interaction in the ensemble of reinforcement aggregates and porous. The conditional and unconditional multipoint correlation functions (CF) of different orders for random structures and elastic modules are required for construction of approximate solutions of the problems.

Usually calculation of CF follow the ‘traditional’ algorithms which used to plot these functions experimentally by processing of fibreglass plastic microslices. Realization of the algorithms have been supposed to usage of an additional co-ordinate net, definition of belonging each point of the net to one of the composite phases and required significant hardware and software cast even in the case of realization of height-performance parallel computational procedures. The results of CF calculation, which carried out on the height-performance cluster of Perm National Research Polytechnic University (64 nodes with peak performance up to 4,096 TFlops and total memory 12 Tbyte) have shown, that usage of 4 nodes (each node contains 2 Barcelona-3 processors) have been reduced the total solution cast up to 6 times and further increasing the number of nodes is inappropriate.

The new method for analytical calculation of conditional and unconditional multipoint CF of the different orders for random structures, stress and strain fields in 2D and 3D composites and high-porous materials was developed on the basis of the proven theorems for geometric sense of conditional probabilities [1, 2]. The general regularities of random fields (such as localization and the presence of the order parameters, i.e. periodic terms in the random fields) were detected. Theorems on the derivative sign of conditional and unconditional correlation functions of the second and third orders at the points corresponding to zero values of arguments, and on the local isotropy of random fields were formulated and proved. Obtained derivatives, which are defined by a ration of the measures for the interphase surface and for the fragment, could be considered as one of a possible conditions for verification and a rejection of existing and developed models for random-structured media.

The authors acknowledge the support of the Russian Foundation for Basic Research (Grant RFBR No 11–01–00910).

REFERENCES

DYNAMICAL STRAINED CONDITION OF A BI-LAYER PLATE ON A RIGID FOUNDATION

A. D. Zamanov and T. R. Suleymanov

Institute of Mathematics and Mechanics, NAS of Azerbaijan, Baku, Azerbaijan

Study of the effect of initial stresses on the dynamic stresses in homogeneous layered materials is of great theoretical and practical importance. Despite the actuality of such problems, research in this area is not sufficient. Previously obtained results can not be used in cases when the laminate is located on the rigid ground. It should be noted that such conditions are characteristic of structural elements, where the basic material is covered with laminate. In the study of dynamic stresses field during forced oscillations in the overlying layers, the inevitable initial stresses occurs.

With help of the model of piecewise-homogeneous body, forced oscillation pre-stretched within two layer slab on the rigid ground is considered by using three-dimensional linearized theory of elastic waves in bodies with initial stresses. It is assumed that the material layers are incompressible. Numerical results are presented for the case when the material stiffness of the lower layer of the material is more than for the upper layer. Based on the obtained results the influence of pre-stretch layers on the oscillation frequency and the normal stresses acting on the surface of the layer between the slab and the rigid foundation are analyzed.

Analysis of the obtained numerical results show that as a result of pre-stretching of the lower layer the absolute values of normal stresses are reduced, but during a preliminary stretching of the upper layer the preliminary values of the normal stretching are increasing. Therefore, pre-stretching of the layers both quantitatively and qualitatively has significant effect on the stress distribution and frequency.

REFERENCE

BEAM BENDING WITH CONSIDERATION OF CORROSION WEAR

A. D. Zamanov\textsuperscript{1,2} and S. A. Gahramanov\textsuperscript{2}

\textsuperscript{1}Institute of Mathematics and Mechanics, NAS Azerbaijan, Baku, Azerbaijan, \textsuperscript{2}Azerbaijan University of Architecture and Construction, Baku, Azerbaijan

It is known that some elements of building structures are exposed to corrosion, which leads to deterioration. This process changes the geometry of the element. Consequently, redistribution of stress-deformed state occurs. Therefore, the study of the corrosive wear remains important subject.

Let’s consider a rectangular beam with a unit width, length $2L$ which is under the uniformly distributed vertical load and with intensity $q$. In this case, the equation of the distribution of the momentum $M$, as a technical theory looks like:

$$M = \frac{1}{2} q(L^2 - x^2), \quad M = -\frac{2}{3} h^3(x,t) \frac{\partial^3 W}{\partial x^3},$$

where $W$, $h$ is deflection and thickness of the beam, which difference is determined from wear and tear. Let’s assume that the wear rate depends not only on the physical-chemical properties of a metal-medium pair, but on the deformation of the corroded surface. If we assume that only the bottom surface of the beam corrodes, i.e. $z = -H$, then the equation of the wear will be:

$$\frac{\partial h}{\partial t} = -\nu - k h \frac{\partial^3 W}{\partial x^3}; \quad h = h_0 \text{ then } t = 0$$

where $\nu$ is the corrosion rate; $\kappa$ is proportionality coefficient \cite{1}; $h$ is the initial value of the thickness of the beam, $t$ is time. Considering expression for momentum we obtain:

$$\frac{\partial h}{\partial t} = -\nu + \frac{k}{4} q(L^2 - x^2) h^{-2}; \quad h = h_0 \text{ then } t = 0.$$

The solution of the obtained equation can be represented in the following form:

$$t = \frac{h_0 - h}{\nu} - \frac{1}{2} \frac{a(x)}{\nu} \ln \left[ \frac{h - a(x)}{h + a(x)} \cdot \frac{h_0 + a(x)}{h_0 - a(x)} \right]; \quad a^2(x) = \frac{1}{\nu} \cdot \frac{3k}{4} q(L^2 - x^2).$$

Hence we obtain that the wear of the beam thickness varies over time and the coordinate $x$. In the case of $k = 0$, we get $h = h(t) = h_0 - ut$, i.e. the change in thickness uniformly along its length. Note that this expression is true if $t < t_0 (h > 0)$, where $t_0$ is the time for complete wear along the beam thickness \cite{1}. It is clear that the most of wear occurs at $x = 0$. Then, wearing time of the rod at $x = 0$ is determined by the following expression:

$$t_1 = t_0 - \frac{1}{2} \frac{a(0)}{\nu} \ln \left[ \frac{h_0 + a(0)}{h_0 - a(0)} \right]; \quad a^2(0) = \frac{1}{\nu} \cdot \frac{3k}{4} L^2.$$

REFERENCE

1. Заманов А.Д., Кахраманов С.А. Продольные колебания стержня, находящегося в грунте с учетом коррозии. Международный журнал “Механика-машиностроение”. Баку, 2007 № 2, стр. 4 – 6.
ON THE ACCURACY OF THE “EQUIVALENT CYLINDER” APPROACH IN MEASURING THE LOCAL INTERFACIAL SHEAR STRENGTH IN THE PULL-OUT TEST

S. Zhandarov\textsuperscript{1,2} and E. Mäder\textsuperscript{1}

\textsuperscript{1}Leibniz Institute of Polymer Research, 01069 Dresden, Germany
\textsuperscript{2}V. A. Bely Metal-Polymer Research Institute of the National Academy of Sciences of Belarus, 246050, Gomel, Belarus

The pull-out test is one of the most popular techniques of studying load transfer at fiber–matrix interfaces and determining interfacial parameters. In particular, the local interfacial shear strength (IFSS), the most important parameter characterizing fiber–matrix adhesion, can be calculated from the value of the debond force, $F_d$, measured in the test, using one-dimensional shear-lag stress analysis. The common practice of this approach is that the real specimen shape, close to a spherical segment, often with the meniscus around the fiber, is approximated by an “equivalent cylinder” — a cylinder with the height equal to the embedded length and the radius chosen so that the cylinder volume is equal to the matrix volume within the embedded zone. However, the parameters of stress transfer in fiber–matrix systems are very sensitive to the fiber volume content, $V_f$, in the specimen. In real matrix droplets, $V_f$ is very large (close to 1) near the fiber entry point, but decreases fast along the specimen axis; in contrast, in the equivalent cylinder it is constant and rather small. In this paper, we compared two models of the pull-out specimen — the equivalent cylinder and the platelet model [1] in which the matrix droplet is represented as a set of thin contacting disks with the diameters varying along the embedded fiber to approximate the real droplet shape. Analytical expressions for the profiles of the fiber tensile stress and the interfacial shear stress have been derived for the matrix droplet in the shape of a spherical segment [2], and numerical solutions have been obtained for real-shaped matrix droplets with menisci [3]. Using these solutions, we analyzed the process of crack initiation and propagation in the platelet model and investigated the effect of the specimen shape on the force–displacement curves. Though the difference between the fiber tensile stress profiles from the “equivalent cylinder” and platelet models is rather small, the behavior of the interfacial shear stress, especially in the fiber-rich regions near the fiber entry point, is substantially different for these two models. In particular, the crack propagation immediately after initiation (at short crack length) is always stable, even in the case of negligible friction and residual thermal stresses, if the specimen includes a fiber-rich region. The higher interfacial stress near the loaded fiber end in the platelet model results in earlier (at a lower $F_d$ value) crack initiation and smoother shape of the force–displacement curve, as compared with the equivalent cylinder model. The decrease in the $F_d$ value, evaluated by visual registration of the “kink” in the force–displacement curve, can be as large as 10–20%; this means, in turn, that the calculated IFSS value is underestimated by 5–25%, depending mostly on the embedded length, if the equivalent cylinder is used instead of the real droplet shape. A method of correction to the equivalent cylinder model in order to avoid this underestimation is proposed.

REFERENCES

TESTING OF ABRASIVE WEAR OF FML COMPOSITES BASED ON A FIBREGLASS WOVEN FABRIC

S. J. Zolkiewski

Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Mechanical Engineering Faculty, Silesian University of Technology, 44-100, Gliwice, Poland
e-mail: slawomir.zolkiewski@polsl.pl

The tested specimens are fibre-metal laminates (FMLs) made of a steel plate and fibreglass laminate plate. During fabrication of composites epoxide resin and polyester resin were used as a warp. The fibre-metal composites combine good points of metal and laminates, such as locking of expansion of cracks on the composite surface under multiple loading [1]. They also have very good force versus displacement characteristics. This type of materials is popular and very widely applied in many technical systems. The most common implementations are connections of materials consisted of different fabrics, connections of laminate materials with many layers in their structure and with different configurations between metals and laminates.

In order to define the degree of abrasive wear of tested specimens and compare the results of testing the methodology of research was assumed as follows: abrasive test and the visual valuation, measurement of mass decrement, measurement of geometrical structure of the profile.

In the Fig. 1 the exemplary results for abrasive tests of FML based on polyester fibreglass laminate are presented. Thanks to the results of the abrasive wear tests, it is possible to estimate and compare the surface of the specimens together with the joint of the fibreglass laminate with different basis weight of fabrics. It is also possible to define the most proper material qualities for the purpose of an optimal FML fabrication. The measurements of mass decrement were taken with the accuracy of 0.001 g. The mass of each specimen was weighed before and after the test. Basing on the obtained results mass decrement of the particular specimen was compared. The measurements were taken in accordance with the EN ISO 12947-3:1998 norm - Textiles. Textiles - Determination of the abrasion resistance of fabrics by the Martindale method - Part 3: Determination of mass loss.

REFERENCES


236
The fibre-metal laminates made of a steel plate and fibreglass laminate plate were tested in the special laboratory stands. Epoxide resin and polyester resin were used as warp to fabricate the composites. The fibre-metal laminates combine advantages of metals and laminates. Good points of such a type materials are locking of expansion of cracks on the composite surface under cyclic loading [1]. These materials have very good force versus displacement characteristics as well. They are very popular and widely applied in technical systems. They can be put to use in connecting materials made of various fabrics, connecting high number layer laminates and most of all connecting metals and laminates.

In the Fig. 1 the exemplary measured values of the strains and forces for the five layer roving laminate with basis weight of 400 g.s.m. connected with the metal sheet plate with thickness of 0.5 mm by eight M4 (metric thread of 4 mm) screws. In this paper there are the results of testing fibrous composite materials connected in bolt joints presented. Composite materials reinforced with fiberglass, carbon and aramid fibers are considered. The impact of number of applied screws in a joint on a strength properties was investigated. The connections by means of eight or sixteen screws were compared. A major problem of modelling the composites is assuming physical and material parameters of the analyzed elements.

REFERENCES

## AUTHORS INDEX

<table>
<thead>
<tr>
<th>Name</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abolins J.</td>
<td>39</td>
</tr>
<tr>
<td>Abu F.</td>
<td>20</td>
</tr>
<tr>
<td>Ahmad M.</td>
<td>20</td>
</tr>
<tr>
<td>Ahmed M.</td>
<td>21</td>
</tr>
<tr>
<td>Aizikovich S.</td>
<td>22</td>
</tr>
<tr>
<td>Akbarov S. D.</td>
<td>23, 24, 25, 26, 27, 28, 119</td>
</tr>
<tr>
<td>Akhundov V. M.</td>
<td>29, 30, 31</td>
</tr>
<tr>
<td>Akishin P.</td>
<td>32, 33, 54, 126</td>
</tr>
<tr>
<td>Alexeeva S.</td>
<td>226</td>
</tr>
<tr>
<td>Al-Khudairi O.</td>
<td>34</td>
</tr>
<tr>
<td>Allen D. H.</td>
<td>35</td>
</tr>
<tr>
<td>Allikas G.</td>
<td>36, 100</td>
</tr>
<tr>
<td>Almajid A. A.</td>
<td>82</td>
</tr>
<tr>
<td>Alrousan R.</td>
<td>37, 97</td>
</tr>
<tr>
<td>Amenzadeh R. Yu.</td>
<td>38</td>
</tr>
<tr>
<td>Anderssons J.</td>
<td>155, 163, 203</td>
</tr>
<tr>
<td>Aniskevich A.</td>
<td>33, 40, 88, 208</td>
</tr>
<tr>
<td>Aniskevich K.</td>
<td>33, 41, 63</td>
</tr>
<tr>
<td>Anoshkin A. N.</td>
<td>42, 43, 44</td>
</tr>
<tr>
<td>Antonakopoulos N.</td>
<td>86</td>
</tr>
<tr>
<td>Arbaoui A.</td>
<td>45</td>
</tr>
<tr>
<td>Arda I.</td>
<td>98</td>
</tr>
<tr>
<td>Arnaoutov A.</td>
<td>46, 47, 176</td>
</tr>
<tr>
<td>Arshantitsa A.</td>
<td>48</td>
</tr>
<tr>
<td>Arumugam K.</td>
<td>71</td>
</tr>
<tr>
<td>Aruniiit A. R.</td>
<td>36, 49, 100</td>
</tr>
<tr>
<td>Aryutkin K. N.</td>
<td>50</td>
</tr>
<tr>
<td>Aslanov M. S.</td>
<td>179</td>
</tr>
<tr>
<td>Ayadi Z.</td>
<td>141, 142</td>
</tr>
<tr>
<td>Babenko F. I.</td>
<td>51, 182</td>
</tr>
<tr>
<td>Babin A.</td>
<td>139</td>
</tr>
<tr>
<td>Babuscu Yesil U.</td>
<td>26</td>
</tr>
<tr>
<td>Bacinskas D.</td>
<td>153</td>
</tr>
<tr>
<td>Bae K. C.</td>
<td>52</td>
</tr>
<tr>
<td>Baier A.</td>
<td>146</td>
</tr>
<tr>
<td>Balci E.</td>
<td>53</td>
</tr>
<tr>
<td>Banov M.</td>
<td>221</td>
</tr>
<tr>
<td>Bárboas G.</td>
<td>158</td>
</tr>
<tr>
<td>Barkanov E.</td>
<td>32, 54, 122</td>
</tr>
<tr>
<td>Bartule M.</td>
<td>94</td>
</tr>
<tr>
<td>Baştürk S. B.</td>
<td>55</td>
</tr>
<tr>
<td>Belkova I.</td>
<td>228</td>
</tr>
<tr>
<td>Belouettar S.</td>
<td>54</td>
</tr>
<tr>
<td>Berger Ch.</td>
<td>94</td>
</tr>
<tr>
<td>Berzina – Cimdina L.</td>
<td>206</td>
</tr>
<tr>
<td>Beverte I.</td>
<td>56</td>
</tr>
<tr>
<td>Bezemelintsyn A. V.</td>
<td>189</td>
</tr>
<tr>
<td>Bhutto M. A.</td>
<td>57</td>
</tr>
<tr>
<td>Bienias J.</td>
<td>58, 59, 60</td>
</tr>
<tr>
<td>Bisagni C.</td>
<td>83</td>
</tr>
<tr>
<td>Bitenieks J.</td>
<td>61</td>
</tr>
<tr>
<td>Bochkov I.</td>
<td>62</td>
</tr>
<tr>
<td>Bondon A.</td>
<td>215</td>
</tr>
<tr>
<td>Bordado J. C.</td>
<td>196</td>
</tr>
<tr>
<td>Borisova A.</td>
<td>63, 215</td>
</tr>
<tr>
<td>Braun U.</td>
<td>214</td>
</tr>
<tr>
<td>Brauns J.</td>
<td>197</td>
</tr>
<tr>
<td>Brovkina J.</td>
<td>194, 195</td>
</tr>
<tr>
<td>Bumanis G.</td>
<td>204</td>
</tr>
<tr>
<td>Buschhorn S. T.</td>
<td>205</td>
</tr>
<tr>
<td>Byrne J. A.</td>
<td>21</td>
</tr>
<tr>
<td>Cabulis U.</td>
<td>84</td>
</tr>
<tr>
<td>Camanho P. P.</td>
<td>140</td>
</tr>
<tr>
<td>Camilleri D.</td>
<td>74</td>
</tr>
<tr>
<td>Camušcu N.</td>
<td>53</td>
</tr>
<tr>
<td>Carjova K.</td>
<td>221</td>
</tr>
<tr>
<td>Cazan O.</td>
<td>64</td>
</tr>
<tr>
<td>Chang I.-Ta.</td>
<td>120</td>
</tr>
<tr>
<td>Chate A.</td>
<td>91</td>
</tr>
<tr>
<td>Chatsy R.</td>
<td>65, 66, 163</td>
</tr>
<tr>
<td>Chernyavskaya S.</td>
<td>134</td>
</tr>
<tr>
<td>Cho Y. J.</td>
<td>67</td>
</tr>
<tr>
<td>Choi J. M.</td>
<td>52</td>
</tr>
<tr>
<td>Christiansen J. C.</td>
<td>69</td>
</tr>
<tr>
<td>Coelho J. F. J.</td>
<td>196</td>
</tr>
<tr>
<td>Costa J. D. M.</td>
<td>80</td>
</tr>
<tr>
<td>Dandurand B.</td>
<td>226</td>
</tr>
<tr>
<td>Daničchuk E. N.</td>
<td>129</td>
</tr>
<tr>
<td>Dariushi S.</td>
<td>68</td>
</tr>
<tr>
<td>Deng J.</td>
<td>191</td>
</tr>
<tr>
<td>Drozdov A. D.</td>
<td>69</td>
</tr>
<tr>
<td>Dubkova V. I.</td>
<td>70</td>
</tr>
<tr>
<td>Duraisamy S.</td>
<td>71</td>
</tr>
<tr>
<td>Dzenis Yu.</td>
<td>72, 147</td>
</tr>
<tr>
<td>Dordoi J.</td>
<td>120</td>
</tr>
<tr>
<td>Dorodochuk L.</td>
<td>144</td>
</tr>
<tr>
<td>Dogomazov A.</td>
<td>129</td>
</tr>
<tr>
<td>Doranov M. S.</td>
<td>179</td>
</tr>
<tr>
<td>Ayadi Z.</td>
<td>141, 142</td>
</tr>
<tr>
<td>Babenko F. I.</td>
<td>51, 182</td>
</tr>
<tr>
<td>Babin A.</td>
<td>139</td>
</tr>
<tr>
<td>Babuscu Yesil U.</td>
<td>26</td>
</tr>
<tr>
<td>Bacinskas D.</td>
<td>153</td>
</tr>
<tr>
<td>Bae K. C.</td>
<td>52</td>
</tr>
<tr>
<td>Baier A.</td>
<td>146</td>
</tr>
<tr>
<td>Balci E.</td>
<td>53</td>
</tr>
<tr>
<td>Banov M.</td>
<td>221</td>
</tr>
<tr>
<td>Bárboas G.</td>
<td>158</td>
</tr>
<tr>
<td>Barkanov E.</td>
<td>32, 54, 122</td>
</tr>
<tr>
<td>Bartule M.</td>
<td>94</td>
</tr>
<tr>
<td>Baştürk S. B.</td>
<td>55</td>
</tr>
<tr>
<td>Belkova I.</td>
<td>228</td>
</tr>
<tr>
<td>Belouettar S.</td>
<td>54</td>
</tr>
<tr>
<td>Berger Ch.</td>
<td>94</td>
</tr>
<tr>
<td>Berzina – Cimdina L.</td>
<td>206</td>
</tr>
<tr>
<td>Beverte I.</td>
<td>56</td>
</tr>
<tr>
<td>Bezemelintsyn A. V.</td>
<td>189</td>
</tr>
<tr>
<td>Bhutto M. A.</td>
<td>57</td>
</tr>
<tr>
<td>Bienias J.</td>
<td>58, 59, 60</td>
</tr>
<tr>
<td>Bisagni C.</td>
<td>83</td>
</tr>
<tr>
<td>Bitenieks J.</td>
<td>61</td>
</tr>
<tr>
<td>Bochkov I.</td>
<td>62</td>
</tr>
<tr>
<td>Bondon A.</td>
<td>215</td>
</tr>
<tr>
<td>Bordado J. C.</td>
<td>196</td>
</tr>
<tr>
<td>Borisova A.</td>
<td>63, 215</td>
</tr>
<tr>
<td>Braun U.</td>
<td>214</td>
</tr>
<tr>
<td>Brauns J.</td>
<td>197</td>
</tr>
<tr>
<td>Brovkina J.</td>
<td>194, 195</td>
</tr>
<tr>
<td>Bumanis G.</td>
<td>204</td>
</tr>
<tr>
<td>Buschhorn S. T.</td>
<td>205</td>
</tr>
<tr>
<td>Byrne J. A.</td>
<td>21</td>
</tr>
<tr>
<td>Cabulis U.</td>
<td>84</td>
</tr>
<tr>
<td>Camanho P. P.</td>
<td>140</td>
</tr>
<tr>
<td>Camilleri D.</td>
<td>74</td>
</tr>
<tr>
<td>Camušcu N.</td>
<td>53</td>
</tr>
<tr>
<td>Carjova K.</td>
<td>221</td>
</tr>
<tr>
<td>Cazan O.</td>
<td>64</td>
</tr>
<tr>
<td>Chang I.-Ta.</td>
<td>120</td>
</tr>
<tr>
<td>Chate A.</td>
<td>91</td>
</tr>
<tr>
<td>Chatsy R.</td>
<td>65, 66, 163</td>
</tr>
<tr>
<td>Chernyavskaya S.</td>
<td>134</td>
</tr>
<tr>
<td>Cho Y. J.</td>
<td>67</td>
</tr>
<tr>
<td>Choi J. M.</td>
<td>52</td>
</tr>
<tr>
<td>Christiansen J. C.</td>
<td>69</td>
</tr>
<tr>
<td>Coelho J. F. J.</td>
<td>196</td>
</tr>
<tr>
<td>Costa J. D. M.</td>
<td>80</td>
</tr>
<tr>
<td>Dandurand B.</td>
<td>226</td>
</tr>
<tr>
<td>Daničchuk E. N.</td>
<td>129</td>
</tr>
<tr>
<td>Dariushi S.</td>
<td>68</td>
</tr>
<tr>
<td>Deng J.</td>
<td>191</td>
</tr>
<tr>
<td>Drozdov A. D.</td>
<td>69</td>
</tr>
<tr>
<td>Dubkova V. I.</td>
<td>70</td>
</tr>
<tr>
<td>Duraisamy S.</td>
<td>71</td>
</tr>
<tr>
<td>Dzenis Yu.</td>
<td>72, 147</td>
</tr>
<tr>
<td>Dordoi J.</td>
<td>120</td>
</tr>
<tr>
<td>Dorodochuk L.</td>
<td>144</td>
</tr>
<tr>
<td>Dogomazov A.</td>
<td>129</td>
</tr>
<tr>
<td>Doranov M. S.</td>
<td>179</td>
</tr>
<tr>
<td>Ayadi Z.</td>
<td>141, 142</td>
</tr>
<tr>
<td>Babenko F. I.</td>
<td>51, 182</td>
</tr>
<tr>
<td>Babin A.</td>
<td>139</td>
</tr>
<tr>
<td>Babuscu Yesil U.</td>
<td>26</td>
</tr>
<tr>
<td>Bacinskas D.</td>
<td>153</td>
</tr>
<tr>
<td>Bae K. C.</td>
<td>52</td>
</tr>
<tr>
<td>Baier A.</td>
<td>146</td>
</tr>
<tr>
<td>Balci E.</td>
<td>53</td>
</tr>
<tr>
<td>Banov M.</td>
<td>221</td>
</tr>
<tr>
<td>Bárboas G.</td>
<td>158</td>
</tr>
<tr>
<td>Barkanov E.</td>
<td>32, 54, 122</td>
</tr>
<tr>
<td>Bartule M.</td>
<td>94</td>
</tr>
<tr>
<td>Baştürk S. B.</td>
<td>55</td>
</tr>
<tr>
<td>Belkova I.</td>
<td>228</td>
</tr>
<tr>
<td>Belouettar S.</td>
<td>54</td>
</tr>
<tr>
<td>Berger Ch.</td>
<td>94</td>
</tr>
<tr>
<td>Berzina – Cimdina L.</td>
<td>206</td>
</tr>
<tr>
<td>Beverte I.</td>
<td>56</td>
</tr>
<tr>
<td>Bezemelintsyn A. V.</td>
<td>189</td>
</tr>
<tr>
<td>Bhutto M. A.</td>
<td>57</td>
</tr>
<tr>
<td>Bienias J.</td>
<td>58, 59, 60</td>
</tr>
<tr>
<td>Bisagni C.</td>
<td>83</td>
</tr>
<tr>
<td>Bitenieks J.</td>
<td>61</td>
</tr>
<tr>
<td>Bochkov I.</td>
<td>62</td>
</tr>
</tbody>
</table>