Fatigue Of Composites Unitn

Experimental and Applied Mechanics, Volume 4: Proceedings of the 2012 Annual Conference on Experimental and Applied Mechanics, the fourth volume of seven from the Conference, brings together 54 contributions to this important area of research and engineering. The collection presents early findings and case studies on fundamental and applied aspects of Experimental and Applied Mechanics, including papers on: Fracture & Fatigue Microscale & Microstructural Effects in Fatigue & Fracture Material Applications Composite Characterization Using Digital Image Correlation Techniques Multi-Scale Simulation and Testing of Composites Residual Stress Inverse Problems/Hybrid Methods Nano-Composites Microstructure Material Characterization Modeling and Uncertainty Quantification Impact Behavior of Composites

Fatigue of Textile Composites provides a current, state-of-art review on recent investigations on the fatigue behavior of composite materials, mainly those reinforced with textiles. As this particular group of composite materials is extremely important for a wide variety of industrial applications, including automotive, aeronautical, and marine, etc., mainly due to their peculiarities and advantages with respect to unidirectional laminated composites, the text presents comprehensive information on the huge variety of interlacement geometric architectures that are suitable for a broad range of different applications, their excellent drapability and versatility, which is highly important for complex double-curvature shape components and three-dimensional woven fabrics without plane reinforcement, and their main mechanical characteristics which are currently in high demand from industry. Presents the current state-of-the-art investigations on fatigue behavior of composite materials, mainly those reinforced with textiles Contains invaluable information pertaining to a wide variety of industries, including automotive, aeronautical, and marine, amongst others Provides comprehensive information on the huge variety of interlacement geometric architectures that are suitable for a broad range of different applications

In this report Dr Lewis surveys the current state of the art in designing with plastics, in terms of materials properties and processing technologies. He also considers the legal implications of intellectual property and product liability, as well as ergonomic and aesthetic design, parts consolidation and recyclability. His review is supported throughout by references to key processes and applications, including many well known consumer products, and further information can be derived from the 435 abstracts of published papers which complete the report.

Summary

Polymers, Ceramics, Composites Alert

Open Hole and Post-impact Compression Fatigue of Stitched and Unstitched Carbon/epoxy Composites

Advanced High-Temperature Structural Materials

Investigation of Composite Materials Property Requirements for Sonic Fatigue Research

It is generally agreed that a unidirectional composite is the fundamental unit from which composite structures are constructed. By subjecting this material to three separate loading conditions, that is, axial, transverse, and shear loadings, the basic stiffness and strength properties of the composite can be predicted in terms of the material and geometric properties of the constituents. These 'micromechanics' analyses are presented, along with a detailed presentation of numerical results and a discussion of their practical significance. Analytical results have been compared with other analyses and with experimental data generated during this investigation. In addition, a preliminary discussion is given to the cyclic fatigue behavior of unidirectional composites. An S glass-epoxy system has been utilized in tests to date. Properties of boron-epoxy composites, including cross-ply and angle-ply laminates subjected to uniaxial tension, have been experimentally determined and results compared with analytical predictions. The satisfactory agreement obtained supports the assumption that the analysis, originally verified for glass-epoxy composites, is equally valid for boron-epoxy systems. (Author).

Materials that possess low-weight, high-temperature strength and stability in corrosive environments are required for many advanced applications. Among competing materials, ceramic matrix composites (CMCs) are the leading candidates. As with all composite systems, ceramic composites are composed of two of more constituents that must maintain identity and properties in the final structure. In fact, it is the combination of constituent properties that produces the desired mechanical response in these advanced structural materials. This book from MRS focuses on ceramic matrix composites, and offers an interdisciplinary perspective on the many unique challenges in design, processing, characterization and testing that they present. Topics include: reinforcements and matrices; matrix materials and processing; composite processing and properties; testing and design; modeling of interfacial behavior; interface test methodologies; chemical vapor infiltration; experimental verification of interface behavior; modification and control of interface properties; and environmental effects.

A fatigue damage computational algorithm utilizing a multiaxial, isothermal, continuum-based fatigue damage model for unidirectional metal-matrix composites has been implemented into the commercial finite element code MARC using MARC user subroutines. Damage is introduced into the finite element solution through the concept of effective stress that fully couples the fatigue damage calculations with the finite element deformation solution. Two applications using the fatigue damage algorithm are presented. First, an axisymmetric stress analysis of a circumferentially reinforced ring, wherein both the matrix cladding and the composite core were assumed to behave elastic-perfectly plastic. Second, a micromechanics analysis of a fiber/matrix unit cell using both the finite element method and the generalized method of cells (GMC). Results are presented in the form of S-N curves and damage distribution plots.

Advanced fibre-reinforced polymer (FRP) composites for structural applications

Fatigue Evaluation of Composite-reinforced, Integrally Stiffened Metal Panels

Woven Composites

It Based Manufacturing

A Coupled/Uncoupled Computational Scheme for Deformation and Fatigue Damage Analysis of Unidirectional Metal-Matrix Composites

Manufacturing, Properties and Applications

In recent years, the fabrication technologies for the production of advanced polymer composites have been revolutionised by sophisticated manufacturing techniques. These methods have enabled polymer composite materials to produce good quality laminates with minimal voids and accurate fibre alignment. This book familiarises and provides a background to the understanding and use of advanced polymer composites in the civil infrastructure; numerous examples have been provided to illustrate the use and versatility of the material. Furthermore, the book discusses the current fabrication techniques, design methods and formulae for the design of structural composite systems. In addition it discusses the fundamentals of geosynthetics used in geotechnical engineering. The book introduces the fibres and matrices that are used to manufacture composites, their mechanical and in-service properties and their long term loading characteristics; all these properties are specifically associated with the construction industry. The chapters then discuss the design aspects for 'all composite' units, as well as systems used for the renewal of civil infrastructure. Finally, the book demonstrated the unique possibilities of combining composites with conventional materials to form units in which the various materials making up the unit are loaded in the mode that specifically suits their mechanical characteristics.

Wind energy is gaining critical ground in the area of renewable energy, with wind energy being predicted to provide up to 8% of the world’s consumption of electricity by 2021. Advances in wind turbine blade design and materials reviews the design and functionality of wind turbine rotor blades as well as the requirements and challenges for composite materials used in both current and future designs of wind turbine blades. Part one outlines the challenges and developments in wind turbine blade design, including aerodynamic and aeroelastic design features, fatigue loads on wind turbine blades, and characteristics of wind turbine blade airfoils. Part two discusses the fatigue behavior of composite wind turbine blades, including the micromechanical modelling and fatigue life prediction of wind turbine blade composite materials, and the effects of resin and reinforcement variations on the fatigue resistance of wind turbine blades. The final part of the book describes advances in wind turbine blade materials, development and testing, including biobased composites, surface protection and coatings, structural performance testing and the design, manufacture and testing of small wind turbine blades. Advances in wind turbine blade design and materials offers a comprehensive review of the recent advances and challenges encountered in wind turbine blade materials and design, and will provide an invaluable reference for researchers and innovators in the field of wind energy production, including materials scientists and engineers, wind turbine blade manufacturers and maintenance technicians, scientists, researchers and academics. Reviews the design and functionality of wind turbine rotor blades Examines the requirements and challenges for composite materials used in both current and future designs of wind turbine blades Provides an invaluable reference for researchers and innovators in the field of wind energy production

This chapter will introduce advances in properties, production and manufacturing techniques of the advanced polymer/fibre composite materials that are utilised in the manufacture of machines that produce sustainable energy. discussed the various methods of transferring wind, tidal, wave and solar energies into electrical power and this chapter will show how advanced composites are utilised in these various machines. Furthermore, it will suggest methods for the repair, maintenance and recycling of advanced polymer composite wind turbine blades. Finally, the future trends of sustainable energy systems and the role that polymers and polymer/fibre composites will have in their manufacture/fabrication will be evaluated.

Strength and Fatigue of Three Glass Fiber Reinforced Composite Bridge Decks with Mechanical Deck to Stringer Connections

Experimental and Applied Mechanics, Volume 4

20. Advanced fibre-reinforced polymer (FRP) composite materials for sustainable energy technologies

Thermal Fatigue in Ceramics and Ceramic Matrix Composites

Proceedings of the 2012 Annual Conference on Experimental and Applied Mechanics

Advances in wind turbine blade design and materials

A life prediction model is being developed by the authors for application to metal matrix composites (MMC's). The systems under study are continuous silicon carbide fibers imbedded in titanium matrix. The model utilizes a computationally based framework based on thermodynamics and continuum mechanics, and accounts for matrix inelasticity, damage evolution, and environmental degradation due to oxidation. The computational model utilizes the finite element method, and an evolutionary analysis of a unit cell is accomplished via a time stepping algorithm. The computational scheme accounts for damage growth such as fiber-matrix debonding, surface cracking, and matrix cracking via the inclusion of cohesive zone elements in the unit cell. These elements are located based on experimental evidence also obtained by the authors. The current paper outlines the formulation utilized by the authors to solve this problem, and recent results are discussed. Specifically, results are given for a four-ply unidirectional composite subjected to cyclic fatigue loading at 650°C both in air and inert gas. The effects of oxidation on the life of the composite are predicted with the model, and the results are compared to limited experimental results.

This report describes an evaluation study for the application of stereo-X-radiography as a tool for three dimensional visualization and quantitative assessment of mechanical damage in graphite-epoxy structural materials. Comparison of image quality produced using X-ray opaque liquid penetrant materials was made for stereo-X-radiographs of panels that contained mechanical damage. A new X-ray opaque penetrant material was formulated and used for development of a high resolution stereo-X-radiographic technique. The technique was used to document damage accumulation in a series of pre-damaged panels during incremental tension-tension fatigue loading. The high resolution technique was shown to be useful in assessment of accumulated damage and in quantitative location of the damage within a panel. Features of the technique include use of a new X-ray opaque penetrant formulation, use of a unique penetrameter, 'soft radiation' and a fine grained X-ray film.

Residual Stress, Thermomechanics & Infrared Imaging, Hybrid Techniques and Inverse Problems, Volume 8: Proceedings of the 2013 Annual Conference on Experimental and Applied Mechanics, the eighth volume of eight from the Conference, brings together contributions to this important area of research and engineering. The collection presents early findings and case studies on a wide range of areas, including: Advances in Residual Stress Measurement Methods

Residual Stress Effects on Material Performance Optical, Ultrasonic, and Diffraction Methods for Residual Stress Measurement Thermomechanics & Infrared Imaging Inverse Methods Inverse Methods in Plasticity Applications in Experimental Mechanics

Damage and Failure of Composite Materials

Mechanics of Fatigue Damage and Degradation in Random Short-fiber Composites

Residual Stress, Thermomechanics & Infrared Imaging, Hybrid Techniques and Inverse Problems, Volume 8

Prediction of Damage Evolution in Continuous Fiber Metal Matrix Composites Subjected to Fatigue Loading

Biaxial Fatigue Loading of Notched Composites

Recent Advances in Textile Composites

This report presents the results of the first task of a three task program directed at the study of relationship between damage propagation and residual static strength of composite laminates. In Task 1: Preliminary screening, two laminates a 24-Ply 67% 0 deg. fiber and a 32-Ply quasi-isotropic laminate of T300/5208 graphite epoxy material were selected for study. Two damage types were studied, a low velocity impact condition (i.e., simulated tool drop) and a badly drilled hole. An initial study was conducted for each damage type to determine the detailed damage introduction parameters resulting in the selection of one set of impact and one set of poor drilling conditions. Baseline static tension and static compression tests were conducted on each of the four damage/laminate conditions. Stress vs life (S-N) fatigue data were then generated at range ratio R=-1 for each of the four conditions. The damage growth characteristics were monitored on each fatigue specimen using a modified Holscan ultrasonic unit. A subset of the damaged hole specimens was also evaluated in static compression and fatigue (R = -1) using TBE enhanced X-ray methods to monitor damage growth and to assess any detrimental effect of TBE on subsequent behavior of the damage. The results indicate significant reduction in initial static tension and compression strengths for the damaged hole condition in both laminates.

Understanding damage and failure of composite materials is critical for reliable and cost-effective engineering design. Bringing together materials mechanics and modeling, this book provides a complete guide to damage, fatigue and failure of composite materials. Early chapters focus on the underlying principles governing composite damage, reviewing basic equations and mechanics theory, before describing mechanisms of damage such as cracking, breakage and buckling. In subsequent chapters, the physical mechanisms underlying the formation and progression of damage under mechanical loads are described with ample experimental data, and micro- and macro-level damage models are combined. Finally, fatigue of composite materials is discussed using fatigue-life diagrams. While there is a special emphasis on polymer matrix composites, metal and ceramic matrix composites are also described. Outlining methods for more reliable design of composite structures, this is a valuable resource for engineers and materials scientists in industry and academia.

Composite materials are increasingly used in many applications because they offer the engineer a range of advantages over traditional materials. They are often used in situations where a specified level of performance is required, but where the cost of testing the materials under the extremes of those specifications is very high. In order to solve this problem, engineers are turning to computer Modelling to evaluate the materials under the range of conditions they are likely to encounter. Many of these analyses are carried out in isolation, and yet the evaluation of a range of composites can be carried out using the same basic principles. In this new book the editor has brought together an international panel of authors, each of whom is working on the analysis and Modelling of composite materials. The overage of the book is deliberately wide; to illustrate that similar principles and methods can be used to model and evaluate a wide range of materials. It is also hoped that, by bringing together this range of topics, the insight gained in the study of one composite can be recognized and utilized in the study of others. Professional engineers involved in the specification and testing of composite material structures will find this book an invaluable resource in the course of their work. It will also be of interest to those industrial and academic engineers involved in the design, development, manufacture and applications of composite materials.

Fatigue of Textile Composites

Fatigue Behavior of Ceramic Matrix Composites

Tension and Compression Fatigue Response of Unnotched 3D Braided Composites

Proceedings of the 2014 Annual Conference on Experimental and Applied Mechanics

Mechanical Behavior of Fiber-reinforced Composite Materials

Designing with Plastics

Fracture, Fatigue, Failure and Damage Evolution, Volume 5: Proceedings of the 2014 Annual Conference on Experimental and Applied Mechanics, the fifth volume of eight from the Conference, brings together contributions to this important area of research and engineering. The collection presents early findings and case studies on a wide range of areas, including: Mixed Mode Fracture I: Emphasis on Modeling Mixed Mode Fracture II: Emphasis on Experimental Measurements Full-Field Measurements of Fracture Microscale & Microstructural Effects on Mechanical Behavior I: Nanoscale Effects Microscale & Microstructural Effects on Mechanical Behavior II: MEMS Microscale & Microstructural Effects on Mechanical Behavior III: Microstructure Microscale & Microstructural Effects on Mechanical Behavior IV: Shape Memory Alloys Fracture & Fatigue of Composites Fracture & Fatigue for Engineering Applications Wave-Based Techniques in Fracture & Fatigue I Wave-Based Techniques in Fracture & Fatigue II: Acoustic Emissions

This monograph provides a logistic view of IT-Based manufacturing comprising the concept methodology, tools, techniques and applications. Papers written by experts in their fields are organized into different sections covering cutting processes and machine tools, non-traditional manufacturing, joining and forming, manufacturing mechatronics and intelligent manufacturing. Comprises of 129 papers presented by both Indian and International Scientists at the 20th All India Manufacturing Technology, Design and Research Conference. Machining Processes and Machine Tools Non-Traditional Manufacturing Forming and Joining Manufacturing Mechatronics Intelligent Manufacturing Related Topics

Specimens representative of metal aircraft structural components reinforced with boron filamentary composites were manufactured and tested under cyclic loading, cyclic temperature, or continuously applied loading to evaluate some of the factors that affect structural integrity under cyclic conditions. Bonded, stepped joints were used throughout to provide composite-to-metal transition regions at load introduction points. Honeycomb panels with titanium or aluminum faces reinforced with unidirectional boron composite were fatigue tested at constant amplitude under completely reversed loading. Results indicated that the matrix material was the most fatigue-sensitive part of the design, with debonding initiating in the stepped joints. However, comparisons with equal weight all-metal specimens show a 10 to 50 times improved fatigue life. Fatigue crack propagation and residual strength were studied for several different stiffened panel concepts, and were found to vary considerably depending on the configuration. Weight savings up to 30 percent may be realized with the better concepts when compared to all-metal structure. Composite-reinforced metal specimens were also subjected to creep and thermal cycling tests. The creep tests at 50 percent of tensile ultimate load were inconclusive due to large scatter in the limited tests. Thermal cycling of stepped joint tensile specimens resulted in a ten percent decrease in residual strength after 4000 cycles.

Non-Crimp Fabric Composites

Ceramic Matrix Composites: Volume 365

Fracture, Fatigue, Failure, and Damage Evolution, Volume 5

Progressive Failure and Life Prediction of Ceramic and Textile Composites

Proceedings of the 11th International Conference on Composite Materials

Enhanced X-Ray Stereoscopic NDE of Composite Materials

An engineering approach to predict the fatigue life and progressive failure of multilayered composite and textile laminates is presented. Analytical models which account for matrix cracking, statistical fiber failures and nonlinear stress-strain behavior have been developed for both composites and textiles. The analysis method is based on a combined micromechanics, fracture mechanics and failure statistics analysis. Experimentally derived empirical coefficients are used to account for the interface of fiber and matrix, fiber strength, and fiber-matrix stiffness reductions. Similar approaches were applied to textiles using Repeating Unit Cells. In composite fatigue analysis, Walker's equation is applied for matrix fatigue cracking and Heywood's formulation is used for fiber strength fatigue degradation. The analysis has been compared with experiment with good agreement. Comparisons were made with Graphite-Epoxy, C/SiC and Nicalon/CAS composite materials. For textile materials, comparisons were made with triaxial braided and plain weave materials under biaxial or uniaxial tension. Fatigue predictions were compared with test data obtained from plain weave C/SiC materials tested at AS&M. Computer codes were developed to perform the analysis. Composite Progressive Failure Analysis for Laminates is contained in the code CPFail. Micromechanics Analysis for Textile Composites is contained in the code MicroTex. Both codes were adapted to run as subroutines for the finite element code ABAQUS and CPFail-ABAQUS and MicroTex-ABAQUS. Graphic user interface (GUI) was developed to connect CPFail and MicroTex with ABAQUS. Xue, David Y. and Shi, Yucheng and Katikala, Madhu and Johnston, William M., Jr. and Card, Michael F. Marshall Space Flight Center CERAMIC MATRIX COMPOSITES; TEXTILES; FATIGUE LIFE; FAILURE ANALYSIS; LAMINATES; MICROMECHANICS; FRACTURE MECHANICS; COMPUTER PROGRAMS; FINITE ELEMENT METHOD; GRAPHICAL USER INTERFACE...

This unique volume presents the latest developments in the field of advanced woven and braided textile composites, with particular emphasis on computational approaches (finite elements, meshfree). Advanced textile composites such as woven, braided, knitted and stitched fabrics are increasingly being used as structural materials in industrial applications due to their efficiency at reinforcing more directions within a single layer and their ability to conform to surfaces with complex curvatures. Furthermore, textile composites provide improved impact resistance, exceptional thermal, fatigue and corrosion resistance, as well as being easier and cheaper to handle and fabricate compared to UD composites.Topics covered in this book include: 2D and 3D plain, twill, satin woven and braided composites, micro-level and macro-level modelling, failure mechanisms, theoretical studies on cryogenic crack behaviour and the specific deformation modes of textile reinforcements, which include the kinematic and hypoelastic models.This book will be particularly relevant to professional engineers, graduate students and researchers interested in composite materials.

A review of the structural configuration and ground test program is presented. Particular emphasis is placed on the testing of a full-scale stub box test subcomponent and a full span ground test unit. The stub box subcomponent was tested in an environmental chamber under ambient, cold/wet, and hot/wet conditions. The test program included design limit static loads, fatigue spectrum loading to approximately two service lifetimes (with and without damage), design limit damage tolerance tests, and a final residual strength test to a structural failure. The first full-scale ground test unit was tested under ambient condition. The test unit was to have undergone static, fatigue, and damage tolerance tests but a premature structural failure occurred at design limit load during the third limit load test. A failure theory was developed which explains the similarity in types of failure and the large load discrepancy at failure between the two test articles. The theory attributes both failures to high stress concentrations at the edge of the lower rear spar access opening. A second full-scale ground test unit has been modified to incorporate the various changes resulting from the premature failure. The article has been assembled and is active in the test program. (MM).

Textile Composites and Characterisation

Static and Fatigue Damage in High Temperature Composites

Advanced Residual Strength Degradation Rate Modeling for Advanced Composite Structures

Numerical Analysis and Modelling of Composite Materials

Volume 1. Task I: Preliminary Screening

Rapid Fatigue Testing of Glass Fiber Reinforced Polyester Composite

An overview of the micromechanics of materials methods and approaches that can be used for the modelling of wind turbine blade composites is given in this chapter. Using the various modelling methods reviewed here, the strength, stiffness and lifetime of composite materials can be predicted and the suitability of different groups of materials for applications in wind turbine blades can be analysed. The effects of interface and matrix properties, fibre clustering and nanoreinforcement on the strength and lifetime of composites are studied in a number of simulations, and some examples of the analysis of microstructural effects on the strength and fatigue life of composites are provided.

Fatigue of Textile CompositesElsevier

This final report presents the experimental and theoretical work performed in our research program on static and fatigue damage in high temperature composites. The theoretical part focused on development and implementation of a new Transformation Field Analysis (TFA) for inelastic laminates, which employs unit-call, periodic array models, as well as averaging micromechanical models together with any constitutive law for thermo-viscoplastic and other inelastic deformation. Moreover, we have initiated modeling of damage by debonding and frictional sliding at the fiber interface, using the TFA computational scheme and the finite element method. (MM).

October 26-28, 2010, Lille Grand Palais, Lille, France

Impact and Residual Fatigue Behavior of ARALL and AS6/5245 Composite Materials

DC-10 Composite Vertical Stabilizer Ground Test Program

9. Micromechanical modelling of wind turbine blade materials

Advances in Wind Turbine Blade Design and Materials

Proceedings of the 2013 Annual Conference on Experimental and Applied Mechanics

The residual strength of the impact-damaged laminates can be predicted using an analytical model. Both the power law and the wearout models appear to be useful in predicting the fatigue life of the composite laminates. However, because of the slope parameter, the wearout model appears to have a slight edge over the power law model, particularly at low fatigue life and higher applied stress. The strength degradation due to cyclic loading in notched laminates was found to be extremely small up to a million cycles. The residual strength of the fatigue-damaged laminates was found to increase (in proportion to the applied maximum stress with R = 0.1) after a million fatigue cycles. Impact loading followed by cyclic loading was found to be more damaging (in reducing the life of the laminate) than the reversed sequence of loading. The magnitude of the minimum projectile velocity causing catastrophic failure in the laminates tested was found as a function of the applied stress and the number of fatigue cycles.

Non-crimp fabric (NCF) composites are reinforced with mats of straight (non-crimped) fibres, giving them such advantages as strength, ease of handling and low manufacturing costs. Non-crimp fabric composites provides a comprehensive review of the use of NCF composites, their manufacture and applications in engineering. Part one covers the manufacture of non-crimp fabrics, including also topics such as structural stitching and automated defect analysis. Part two goes on to discuss the manufacture of non-crimp fabric composites, with chapters covering such topics as deformability and permeability of NCF. Part three focuses on the properties of NCF composites, with chapters on stiffness and strength, damage progression and fatigue. Finally, part four covers the applications of NCF composites, including chapters on the aerospace and automotive industries as well as wind turbines and helicopter applications. The book concludes with a discussion of cost analysis of NCF composites in engineering applications. With its distinguished editor and international team of expert contributors, Non-crimp fabric composites is an essential reference for composite manufacturers and structural and mechanical engineers in industries using NCF composites, as well as academics with a research interest in the field. Provides a comprehensive review of the use of NCF composites, their manufacture and applications in engineering Reviews the manufacture of non-crimp fabrics, including also topics such as structural stitching and automated defect analysis Examines the properties of NCF composites considering stiffness and strength, damage progression and fatigue

This report describes an experimental program conducted to assess the effect of imbedded delaminations on the compression fatigue behavior of quasi-isotropic, T300/5208, graphite/epoxy laminates. Teflon imbedments were introduced during panel layup to create delaminations. Test specimens were 64-ply thick, and had 3.81 cm square test sections that were unconstrained laterally during compression testing. Static and constant amplitude (R=10, omega= 10 Hz) fatigue tests were conducted. S-N data and half-life residual strength data were obtained. During static compression loading, the maximum deflection of the buckled delaminated region was recorded. Under compression fatigue, growth of the imbedded delamination was identified as the predominant failure mode in most of the test cases. Specimens that exhibited other failures had a single low stiffness ply above the Teflon imbedment. Delamination growth during fatigue was monitored using DIB- enhanced radiography. In specimens with buried delaminations, the dye-penetrant (DIB) was introduced into the delaminated region through a minute laser-drilled hole, using a hypodermic needle. A low-kV, microfocus, X-ray unit was mounted near the test equipment to efficiently record the cyclic growth of buried delaminations on Polaroid film. jg p.6.

Fatigue Degradation in Compressively Loaded Composite Laminates

Advanced Polymer Composites and Polymers in the Civil Infrastructure

Analytical and Experimental Investigation of Aircraft Metal Structures Reinforced with Filamentary Composites. Phase 2: Structural Fatigue, Thermal Cycling, Creep, and Residual Strength

Fatigue/impact Studies in Laminated Composites