Office of Naval Research International Field Office

25. 5th International Conference on Durability Analysis of Composite Systems (DURACOSYS-2001)

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Key Words: *Carbon fiber reinforced polymer (CFRP), Environmental effect, Smart materials, Fatigue, Time-dependent behavior, New testing method*

1. Summary

The DURACOSYS, held at the Tokyo University of Science (TUS) on November 6-9, 2001, focused on mechanical/thermal/environmental durability of advanced composite materials. The subject is directly related to future development of advanced naval shipbuilding. The ONRIFO, AOARD/AFOSR, AROFE and Kodama Foundation sponsored the conference. Prof. Miyano at Kanazawa Institute of Technology (KIT) and Prof. Fukuda at TUS co-chaired the conference. In eleven sessions, 56 oral and poster presentations were made including 5 invited and 5 keynote lectures. The proceeding *"Durability Analysis of Composite Systems 2001"* edited by the co-chairs, A. H. Cardon, K. L. Reifsnider and S. Ogihara has been published by A.A. Balkema Pub. Some selected papers are summarized below. The number in parentheses indicates that of presentations.

Civil Infrastructure (4)

Interfacial Properties Control the Durability of Externally Repaired Infrastructures with Composite Materials (K. Yamaguchi, et al., KIT: Keynote Lecture)

Composite patch systems are being applied for civil infrastructure. The loading capacity of single notched steel beams, which are repaired with externally bonded carbon fiber reinforced polymer (CFRP) sheets, increases under static loading with increasing strength and thickness of the CFRP. The growth rate of fatigue cracks is suppressed when strong and thick CFRPs are used. CF reinforced epoxy resins patched on steel show better resistance to peeling than vinylester, isophthalic and orhtophthalic polyester resins.

Smart Materials (2)

Detection and Suppression of Transverse Cracks in Composite Laminates with Embedded with Fiber Bragg Grating (FBG) Sensors and Shape Memory Alloy (SMA) Film Actuators (N. Takeda and Y. Okabe, University of Tokyo: UOT: Keynote Lecture)

The formation of transverse cracks in 90^o ply of CFRPs was monitored using a small diameter FBG sensor embedded in a 0^o ply adjacent to the $90^o/0^o$ ply interface along the loading direction. A correlation between the width of reflected spectra and crack density has been established. Transverse cracking is suppressed by embedding pre-strained SMA films between CFRP laminates due to the build-up of compressive stresses.

Cure and Health Monitoring of Resin Transfer Molding (RTM) Molded FRP by Using Optical Fiber Strain Sensors (T. Kosaka, et al., Osaka City University)

Cure processing of FRP during RTM was monitored using FBG and extrinsic Fabry-Perot interferometric strain sensors. The embedding configuration and gauge length of optical fiber sensors affect the accuracy of strain measurement. Sensors embedded parallel to the direction of resin flow indicate better strain-temperature relations during the curing than those embedded perpendicularly.

New Test Methods (5)

Dielectric Spectroscopy Technique to Assess the Durability of Adhesively Bonded Composite Joint Structures (P. Boinard, et al., University of Strathclyde, UK)

The effect of water adsorption on the bond strength of adhesive (polymeric woven fiber supported epoxy resin)/CFRP was examined using dielectric spectroscopy. The critical strain energy density for joint failure, which decreases with increasing water content, is correlated with Ng factor given by a product of the dipole density and orientation correlation function.

Environmental Effects (8)

Weight Change and Atomic Force Microscopy (AFM) Study on $Al(OH)_3$ Particles/Vinylester

Composite under Hydrothermal Environments (T. Morii et al., Shonan Institute of Technology)

The weight gain and loss of $Al(OH)_3$ particle/vinylester resin composites, subjected to silane treatment in water at 95°C for 0-1000 h, were analyzed using AFM. Increasing silane treatment suppresses the weight loss of composites exposed to prolonged hydrothermal condition. The AFM observation reveals that the weight loss is related to the removal of filler particles on the composite surface affected by the silane treatment.

Time-Dependent Behavior (4)

Time-Temperature Dependence of Tensile Strength of Unidirectional CFRP (Y. Miyano, et al., KIT: Keynote Lecture)

The tensile strength of unidirectional CFRP strand under constant strain rate (CSR) was found to obey the time-temperature superposition principle. Thus, the master curve of the CRFP strand can be constructed by shifting the failure time using the temperature-time factor, which is the same as that for the storage modulus (E) of matrix resin due to viscoelastic deformation controlling failure mechanism.
http://www.onrifo.navy.mil/Reports/2002/CompDura.doc

The Dynamic Viscoelastic Behavior of Moistened CF/Epoxy Composites (A. Ishisaka, et al., Toyama Prefectural University)

The effect of water adsorption on the viscoelastic properties and glass transition temperature (T_g) was studied in unidirectional CFRPs. The dynamic viscoelasticity of 0° CF is more strongly affected by the water absorption than that of 90° CF and T_g decreases with increasing water content. It has been shown that a change in E induced under air humidity at 60°C can be analyzed by the time-moisture superposition principle.

Fatigue (9)

Bearing Fatigue Behavior of Heat-Resistant Polymer Composites (T. Hamada, et al., UOT)

In CF reinforced bismaleimide composites (G40-800/5260; +45/0/-45/90), the bearing fatigue deformation depends on the testing temperature and clamping force. The fatigue deformation at room temperature more extensively occurs under stronger clamping force while that at 150°C conversely decreases with increasing clamping force.

Fiber Breakage due to Shear Constraint Effect in Plain Woven Glass Fabric Composites under Tension/Shear Biaxial Cyclic Loading (K. Okubo, et al., Doshisha University)

The fracture behavior was studied in plain-woven glass fabric reinforced Vinylester matrix. Static failure proceeds more readily under biaxial tensile/torsional loading than under uniaxial loading due to shear stress-induced fiber breakage. On the contrary, the fatigue life significantly increases under combined tensile/shear stresses.

Interaction of Damage Development and Dissipation in Tensile Fatigue Loading of Composite Laminates (E. K. Gamstedt, Royal Institute of Technology, Sweden and B.F. Sørensen, Risø National Laboratory, Denmark)

The tensile fatigue behavior of unidirectional 0°, $[\pm 10]_{4S}$ and $[\pm 45]_{4S}$ angled laminates with hybrid mixture of carbon/glass fibers has been investigated in terms of the dissipation estimated from the measurement of stiffness, hysteresis loss and temperature field in an insulated testing chamber. Frictional sliding of longitudinal crack faces between carbon and glass fiber bundles is the main source of dissipation for on-axis samples. As the off-axis angle increases, the primary loss arises from the cyclic shear deformation of polymer matrix. In composites with finer dispersion of the constituent, the growth of longitudinal cracks in the matrix is suppressed due to inelastic shear deformation.

Application of Damage Mechanics to Durability (7)
Matrix Cracking Development in CFRP Laminates Induced by Cycling Loadings: Experiments and Analyses (C. Henaff-Gardin and M.C. Lafarie-Frenot, Laboratoire de Mecanique et de Physique des Materiaux, France: Invited lecture)

A change in the strain energy release rate during progressive fatigue cracking in $(0_m/90_n)_s$ CFRP laminates has been analyzed using a non-dimensional characteristic damage variable, which is related to the crack density, the uncracked ply stiffness and the stacking sequence through the layered thickness. The proposed model elucidates the crack density change of the CFRP and is being applied to account for a rapid increase in the crack density under the thermal cycling.

Composite Durability under Corrosive Environment (5)
The Effect of Amount of Hardener on Degradation Behavior of Epoxy Resin in Liquids (Y. Negishi, et al., Tokyo Institute of Technology)

The environmental degradation of epoxy resins containing different amounts of hardener is enhanced in order of sodium hydroxide > sulfuric acid > water. This is because the alkaline hardener promotes the penetration of acid ions.

Applications and Database (5)
Material Characterization and Modeling (6)
Fracture Mechanics (2)

2. Background

The 5th DURACOSYS conference was followed by the first, second and forth ones in Brussels in 1990, 1995 and 1999 and the third one in Virginia Tech. in 1997. The durability analysis is defined as the prediction of the structure integrity of composite systems subjected to mechanical loading history under various environments. Profs. Miyano and Kimpara groups at KIT are currently performing a NICOP, *"Long-Term Durability and Damage Tolerance of Innovative Marine Composites."* The 7th Japan International SAMPE, relevant to advanced composite technology, was held following this conference: *http://www.onrifo.navy.mil/reports/2002/SAMPE.doc*

3. Assessment

Advanced composite materials fail in a more complex manner than the structural alloys. Hence, special durability assessment must be developed for successful application of advanced composite systems to naval shipbuilding. A great deal of research efforts is needed to invent impact durable thick marine composites, which are different from the aircraft component.

4. Points of Contact

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