# Japanese Aerospace Literature This month: *Composite Structures*

**A96-25472 An electron beam nanolithography system and its application to Si nanofabrication.** K. KURIHARA, K. IWADATE, H. NAMATSU, M. NAGASE, H. TAKENAKA, and K. MURASE (NTT Corp., Musashino, Japan), *Japanese Journal of Applied Physics, Part 1* (ISSN 0021-4922), Vol. 34, No. 12B, 1995, pp. 6940–6946. 21 Refs. Documents available from Aeroplus Dispatch.

We present an electron beam nanolithography system which features sub-10-nm beam size over a large 480 x 480 sq micron field and a high 70 kV acceleration voltage with a Zr/O/W thermal field emitter tip. A beam can be deflected at 100 MHz in 2-nm steps, which allows the use of highly sensitive resist. The system is equipped with a highly sensitive YAG detector for electrons backscattered from a registration mark as well as a C/W multilayer knife edge for beam size measurement and focusing. These techniques achieve a beam size of about 6 nm. A 10 nm-scale resist pattern was obtained using ZEP520 resist with this system. Furthermore, Si nanostructures have been obtained by using an image reversal process with ECR plasma oxidation. Photoluminescence was observed from the Si nanowires fabricated with this system. (Author)

**A95-42222 Near-threshold propagation of delamination fatigue cracks in unidirectional CF/PEEK laminates in air and in water.** M. HOJO, S. OCHIAI (Kyoto Univ., Japan), and K. TANAKA (Nagoya Univ., Japan), *Materials Science Research International* (ISSN 1341-1683), Vol. 1, No. 2, 1995, pp. 100–107. 17 Refs. Documents available from Aeroplus Dispatch.

The effects of stress ratio and a water environment on the near-threshold growth of delamination fatigue cracks were investigated with unidirectional laminates made from ICI APC-2 thermoplastic prepregs (AS4/PEEK). Tests were carried out under mode I opening loading by using double cantilever beam specimens. The fatigue crack growth rate near the threshold region was mainly controlled by the stress intensity range rather than the maximum energy release rate and the energy release rate range. The fatigue crack growth resistance of AS4/PEEK laminates was much higher than that of conventional CF/epoxy laminates even near the threshold region. However, the increase in fatigue resistance was smaller than that in fracture toughness. Tests in water did not show large detrimental effects. The crack propagation rate in water was expressed as two power functions of the energy release rate range. The exponent of the power function in the low propagation rate region was smaller than that in the high propagation rate region, and the growth threshold was not observed. The mechanism of the existence of the two power functions was discussed by conducting tests in water at a lower stress cycling frequency. The mesoscopic mechanism of delamination fatigue crack growth in air and in water is discussed on the basis of the fractographic observations made in this study. (Author)

**A95-42221 Finite element analysis of out-of-plane deformation in laminated sheet metals based on an anisotropic plasticity model.** S. IMATANI, T. SAITO, and K. YAMAGUCHI (Kyoto Inst. of Technology, Japan), *Materials Science Research International* (ISSN 1341-1683), Vol. 1, No. 2, 1995, pp. 89–94. 6 Refs. Documents available from Aeroplus Dispatch.

An anisotropic plastic constitutive model is applied to a three-dimensional finite element method based on the updated Lagrangian-type formulation, and the out-of-plane deformation of a laminated sheet metal which is comprised of two different materials, a stainless steel sheet and an aluminum sheet, is analyzed. The constitutive model involves a fourth-order tensor in its representation, by which not only the initial orthotropism but also the subsequent skewed anisotropy can be predicted. The variation of the anisotropic axis is taken into account with reference to the kinematic relationship of the axis before and after the deformation. The conventional laws of both a power formula for work hardening and a normality rule for plastic flow are employed in the model. Before the analysis, simple tension tests in various directions are performed to identify the anisotropic material parameters of each component layer. Since the mechanical properties vary in the thickness direction, a fully three-dimensional scheme is adopted in the numerical analysis. Here, we examine the following three kinds of loading patterns: 1) curl in the transverse direction under a simple tension, 2) deflection in the longitudinal direction in unloaded state following the tension, and 3) strain localization behavior in the large deformation regime. The effect of thickness ratio is discussed from the viewpoint of the reduction of out-of-plane deformation, and the difference due to lamination angle is also examined to clarify the combined effect of planar anisotropy. (Author)

**A94-28754 Material damping analysis of a unidirectional and angle-ply hybrid composite lamina.** V. BABURAJ and Y. MATSUZAKI (Nagoya Univ., Japan), *Proceedings of the 30th Aircraft Symposium*, Tsukuba, Japan, 1992, (A94-28718 09-01), Tokyo, Japan Society for Aeronautical and Space Sciences, 1992, pp. 244–249. 15 Refs. Documents available from Aeroplus Dispatch.

The specific damping capacity of a typical and general intraply hybrid composite lamina is studied. The micromechanic damping theory for a continuous fiber-reinforced intraply composite lamina is presented. Experimental studies confirming the theory are presented. It is found that as much as 70% enhancement of longitudinal specific damping capacity (SDC) is possible by hybridizing 10% Nitinol fibers by volume into a conventional E-glass/IMHS composite lamina. The normal transverse and shear SDC of a lamina predicted by the rule of mixture are found to be higher than those of measure data available in the literature. The normal on-axis SDC of a lamina subjected to off-axis cyclic stress is found to be maximum when the off-axis angle is 60 deg and the same for normal transverse SDC is 30 deg.

**A94-28102 General higher-order theory of laminated composite structures assuming displacements in each layer.** Y. NEGISHI (Fukushima National College of Technology, Iwaki, Japan) and K.-I. HIRASHIMA (Yamanashi Univ., Kofu, Japan), *JSME International Journal, Series A* (ISSN 0914-8809), Vol. 37, No. 3, 1994, pp. 272–281. 21 Refs. Documents available from Aeroplus Dispatch.

A general higher-order approximation theory to analyze static and/or dynamic behaviors of laminated composite structures is established. Theoretical characteristics and validity of the theory are made clear by numerical examples. The theory is formulated by using a modified Hamilton's principle for relaxed displacement continuity requirement, after expanding displacements of each lamina using power series in the thickness direction. The independent unknown variables of this theory are displacement coefficients of each lamina and interlaminar stresses. It is shown that the present theory takes account of the previous theories, and improves the inconsistencies of those theories.

**A95-12451 Analyses of delamination of laminated beams by bending.** M. TOYA, T. MIYAWAKI, and K. KIRIOKA (Kagoshima Univ., Japan), *Proceedings of the 18th International Symposium on Space Technology and Science*, Kagoshima, Japan, 1992, Vol. 1 (A95-12376 01-12), Tokyo, Japan, AGNE Publishing, Inc., 1992, pp. 527–534. 5 Refs. Documents available from Aeroplus Dispatch.

A fracture mechanics-based study is presented on the edge delamination of laminated beams loaded in three- or four-point flexure or subjected to a uniform temperature change. The compliance and the total energy release rate are derived on the bases of the strength of materials theory and the stability of the delamination process is discussed. Finite-element computations are then performed to evaluate the compliance and the modes I and II energy release rates. Numerical results are shown to agree well with those predicted from the theory. Finally, through the analysis of the J-integral for the interlaminar crack, it is concluded that the ratio of the modes I to II energy release rate is nearly independent of cracking length. (Author)

**A94-36999 Optimal design of fiber composite stiffened panel through a penalty function method.** V. BABURAJ (Nagoya Univ., Japan) and V. KALYANARAMAN (Indian Inst. of Technology, Madras, India), *Proceedings of the 31st Aircraft Symposium*, Gifu, Japan, 1993, (A94-36967 12-01), Tokyo, Japan Society for Aeronautical and Space Sciences, 1993, pp. 248–252. 17 Refs. Documents available from Aeroplus Dispatch.

The optimum design procedure of a multi-layered fiber reinforced composite stiffened panel, experiencing inplane and transverse loading and subjected to strength and instability constraints, is discussed. In most of the optimum design procedures presented in the literature for stiffened fiber composite panels, the orientation of the fiber as well as the number of layers are assumed in advance, and the thickness of each layer is treated as the design variable. In the present formulation, the widths of the various elements, the stiffener spacing, the thickness and fiber orientation of each layer of the element are chosen as the design variables, prescribing in advance only the number of layers in each element. The resulting constrained nonlinear optimization problem is solved by using a penalty function based indirect method. (Author)

**N94-28161 Differential scanning calorimetric study of solid state amorphization and crystallization in Zr/Co and Zr/Ni multilayers.** T. AIHARA, JR., K. AOKI, and T. MASUMOTO, Tohoku Univ., Sendai (Japan). Inst. for Materials Research. In its The Science Reports of the Research Institutes, Tohoku University. *Series A: Physics, Chemistry, and Metallurgy*, Vol. 38, No. 1: Amorphous Materials 14, pp. 24–33 (SEE N94-28158 07-26). Documents available from Aeroplus Dispatch.

The processes of Solid State Amorphization (SSA) and subsequent crystallization in Zr/Co and Zr/Ni multilayered thin films have been studied by Differential Scanning Calorimetry (DSC). The thermodynamic values, i.e., the enthalpy change delta H(sub a) and the activation energy E(sub a) for amorphization as well as the enthalpy change delta H(sub x) and the activation energy E(sub x) for crystallization, were evaluated from the DSC experiments. These values were compared with those of the corresponding rapidly quenched amorphous alloys. The activation energies E(sub a), calculated by the modified Ozawa method, are 150 and 132 kJmol(exp −1) for Zr/Co and Zr/Ni multilayers respectively. These values are equivalent to the previously reported activation energy of diffusion of Co or Ni in the rapidly quenched amorphous Zr-Co or Zr-Ni alloys. (Author)

**A94-13247 Free vibrations of symmetrically laminated composite plates.** K. HOSOKAWA (Chubu Univ., Aichi, Japan), T. YADA (Shinko Electric Co., Ltd., Mie, Japan), and T. SAKATA (Chubu Univ., Aichi, Japan), *JSME International Journal, Series C: Dynamics, Control, Robotics, Design and Manufacturing* (ISSN 0914-8825), Vol. 36, No. 3, 1993, pp. 296–300. 8 Refs. Documents available from Aeroplus Dispatch.

In previous papers, authors proposed a numerical approach for analyzing the vibration problem of combined systems. For free vibration analysis, the approach consists of two steps. One is estimating Green's function for a static bending problem of the same plate and the other is to solve a frequency equation. This approach is applied to a symmetrically laminated a fiber-reinforced plastic composite plate. Numerical calculations are carried out for a cantilevered plate and a clamped plate. Green's function of a cantilevered plate is estimated by the Ritz method and that of the clamped plate is obtained by Galerkin's method. Accuracy and convergency of natural frequencies of these plates are discussed. In an attempt to reduce the number of dimensions of the frequency equation, it is assumed that the deflections at five adjacent points on a straight line can be approximated as a parabolic function. This approximation reduces the number of dimensions of the frequency equation and the number of Green's functions. The improved approach was applied to a cantilevered plate. Numerical results showed that the computing time was reduced significantly by the approximation. (Author (revised))

**A93-33106 Inelastic deformation and fracture of laminated graphite/epoxy tubes under multiaxial stress states.** Y. KANAGAWA, S. MURAKAMI, T. ISHIDA, A. UEDA (Nagoya Univ., Japan), and E. TSUSHIMA (Tonen Corp., Corporate Research and Development Lab., Saitama, Japan), *JSME International Journal, Series A: Mechanics and Material Engineering* (ISSN 0914-8809), Vol. 36, No. 1, 1993, pp. 97–103. 18 Refs. Documents available from Aeroplus Dispatch.

The mechanical behavior of laminated graphite/epoxy tubes under multiaxial monotonic loadings was elucidated with special emphasis on the effects of fiber orientation, loading condition, and laminate structure. Tubular specimens of symmetrically laminated graphite/epoxy of five different fiber orientations theta (the angle of fiber measured from the specimen axis) were tested under monotonic combined tension/compression and torsion. Based on the preliminary results of the proceeding paper, the angle theta was specified to be 0 deg, +/−22.5 deg, +/−45 deg, +/−67.5 deg, and +/−78.75 deg. The results of the stress-strain relationships and fracture stress loci are presented. It is shown that stiffness and strength decreased with the increase in the angle theta of fiber orientation measured from the direction of principal stress, and the Tsai-Wu criterion applied very well. (Author (revised))

**A93-15548 Mixed-mode fracture test of CFRP laminates.** M. KIKUCHI and M. KURODA (Tokyo Science Univ., Noda, Japan), *JSME International Journal, Series I* (ISSN 0914-8809), Vol. 35, No. 4, 1992, pp. 496–501. 11 Refs. Documents available from Aeroplus Dispatch.

Mixed-mode (modes I and II) interlaminar fracture toughness of unidirectional reinforced and woven CFRP is evaluated using DCB specimens. A new testing apparatus is made to change the ratio of mode I to II across a wide range. The fracture toughness value is evaluated based on beam theory, and the deformation of the specimen is analyzed by FEM. The relationship between compliance and crack length obtained in the experiment agrees with the results obtained by FEM. The constant fracture toughness value, Gc, which is independent of crack length, is obtained. Due to the decrease of the GI/GII ratio, the fracture toughness value increases. It is shown that the role of mode II changes largely due to the change in the ratio of mode I to II, though the mode I component maintains a nearly constant value. (Author)

**A92-53517 Damping materials for spacecraft structures.** J. FUJIMOTO, R. UGO, K. TODOME (NEC Corp., Kawasaki, Japan), and T. TOMOSHIGE (Mitsui Petrochemical Industries, Ltd., Sodegaura, Japan), *Proceedings of the 17th International Symposium on Space Technology and Science*, Tokyo, Japan, 1990, Vol. 1 (A92-53451 23-12), Tokyo, AGNE Publishing, Inc., 1990, pp. 489–499. 4 Refs. Documents available from Aeroplus Dispatch.

Low-outgas, noninflammable damping materials with high damping capability for spacecraft have been developed using a simple three-element model. The design of damping materials for satellites, crew bays in space shuttles and space stations, and sounding rockets is addressed. The mechanical dynamic properties and application to spacecraft structures of CFRP/damping material laminates are considered. (C.D.)

**A92-42395 Fabrication and evaluation of X-ray multilayer mirrors prepared by laser-induced chemical vapor deposition.** M. SHIN-OGI (Seiko Instruments, Inc., Matsudo, Japan), S. SEKI (Nitto Denko Corp., Ibaraki, Japan), Y. ISHINO, H. NAGATA, and Y. SUZUKI (Nikon Corp., Shinagawa, Japan), *Japanese Journal of Applied Physics, Part 1* (ISSN 0021-4922), Vol. 31, No. 4, 1992, pp. 1219–1224. 18 Refs. Documents available from Aeroplus Dispatch.

This study demonstrates a new preparation process for fabricating X-ray multilayer mirrors. Tungsten/carbon multilayer mirrors were prepared using laser-CVD. The structure and properties of the mirror were examined using X-ray diffraction, synchrotron radiation, and TEM measurements. The reflectivity at a grazing angle of 14.5 deg was observed to be 4.1% at a wavelength of 5 nm. The reflectivity was lower than the ideal reflectivity. The reduction in the reflectivity was caused by the lower-density film (tungsten layer), interface roughness and diffuse interfaces. Furthermore, after annealing at room temperature for two months, the increment of the period of this mirror was about 33%. This was due to the oxidation of tungsten films in W/C (tungsten/carbon multilayer mirror). (Author)

**A92-36042 Stress analysis of an orthotropic laminated slab subjected to transverse load.** H. MATSUMOTO (Tokyo Inst. of Technology, Japan), Y. OGAWA (Toyota Motor Corp., Ltd., Japan), and T. ADACHI (Tokyo Inst. of Technology, Japan), *JSME International Journal, Series I* (ISSN 0914-8809), Vol. 35, No. 2, 1992, pp. 165–169. 5 Refs. Documents available from Aeroplus Dispatch.

Stresses in a slab with three orthotropic laminated layers are analyzed by the three dimensional theory of transversely isotropic elasticity. The slab is subjected to transverse concentrated or distributed load at the center part on the top face. To obtain qualitative knowledge for delamination of carbon fiber reinforced plastic (CFRP) laminates, numerical results of interlaminar stresses are given for graphite/epoxy square laminates. It is shown that shear stresses on the upper interlaminar boundary are larger than those on the lower one. At each interlaminar boundary, shear stresses are maximal just below the concentrated load point or the edge of the distributed load area, although these stresses are zero at the center point. (Author)

**A92-36041 Load and strain histories for CFRP laminates under low-velocity impact.** J.-S. KOOK (Tokyo Inst. of Technology, Japan), M. SUZUKI (Hitachi, Ltd., Mechanical Engineering Research Lab., Tsuchiura, Japan), T. ADACHI, S. UJIHASHI, and H. MATSUMOTO (Tokyo Inst. of Technology, Japan), *JSME International Journal, Series I* (ISSN 0914-8809), Vol. 35, No. 2, 1992, pp. 159–164. 9 Refs. Documents available from Aeroplus Dispatch.

The impulsive response of carbon fiber reinforced plastics (CFRP)-laminated plates are analyzed by using higher-order shear deformation theory and homogeneous anisotropic laminated plate theory. The plate of unidirectional prepregs is simply supported on all four sides and is hit by a spherical steel impactor at its center. The impact load histories are calculated numerically by using the nonlinear integral equation derived from Hertzian contact law. The strain histories of the plate are evaluated using higher-order theory and the numerical impact load histories obtained above. The theoretical results are in good agreement with the experimental results obtained by strain gauges and a piezoelectric transducer. (Author)

**A92-23171 CFRP/Damping-Material Laminates.** J. FUJIMOTO, T. TAMURA (NEC Corp., Resources and Environment Protection Research Lab. Yokohama, Japan), M. ADACHI, K. TODOME (NEC Corp., Space Development Div., Yokohama, Japan), Y. SUZUKI, T. TOMOSHIGE (Mitsui Petrochemical Industries, Ltd., Kimitsu, Japan), and T. TANIMOTO (Shonan Inst. of Technology, Fujisawa, Japan), *Achievement in composites in Japan and the United States, Proceedings of the 5th Japan-U.S. Conference on Composite Materials*, Tokyo, Japan, 1990 (A92-23101 08-24), Tokyo, Japan Society for Composite Materials, 1990, pp. 695–702. 2 Refs. Documents available from Aeroplus Dispatch.

New materials, that possess high damping capability and have high strength property, have been studied in carbon fiber reinforced plastic (CFRP) materials. These materials are referred to in this paper as CFRP/damping-material laminates. CFRP/damping-materials were fabricated using thermoplastic based damping material with an autoclave curing technique. Cantilever beam tests revealed the high damping properties of these laminates. Loss factor values for these laminates are from 5 through 50 times as large as that for conventional CFRP. Tensile test results indicated that damping material interleafing has significant effects on both the tensile strength and the fracture mode. In three different kinds of laminates, the ultimate load showed an increase of roughly 4% in comparison with conventional CFRP. (Author)

**A92-23169 Free vibration analysis of cantilevered composite rectangular plates.** Y. NARITA (Hokkaido Inst. of Technology, Sapporo, Japan) and A. W. LEISSA (Ohio State Univ., Columbus), *Achievement in composites in Japan and the United States, Proceedings of the 5th Japan-U.S. Conference on Composite Materials*, Tokyo, Japan, 1990 (A92-23101 08-24), Tokyo, Japan Society for Composite Materials, 1990, pp. 679–686. 14 Refs. Documents available from Aeroplus Dispatch.

This work presents an analytical approach and accurate numerical results for the free vibration of cantilevered, symmetrically laminated rectangular plates. The problem is solved by the Ritz method, and the natural frequencies are calculated for a wide range of parameters, e.g., composite material constants, fiber angles and stacking sequence. The results are compared to those in the existing literature, and the effects of varying the parameters upon the free vibration characteristics are discussed. (Author)

**A92-23166 Strength optimization of laminated composites using transformed design variables with respect to layer angles.** H. FUKUNAGA (National Aerospace Lab., Chofu, Japan) and G. N. VANDERPLAATS (VMA Engineering, Goleta, CA), *Achievement in composites in Japan and the United States, Proceedings of the 5th Japan-U.S. Conference on Composite Materials*, Tokyo, Japan, 1990 (A92-23101 08-24), Tokyo, Japan Society for Composite Materials, 1990, pp. 645–652. 13 Refs. Documents available from Aeroplus Dispatch.

The present paper treats a minimum weight design of laminated composites under in-plane loading based upon mathematical programming methods. Design variables are layer angles as well as layer thicknesses, and constraints consist of strength and displacement conditions. Use of transformed design variables is proposed to reduce the nonlinearity between the constraints and the layer angles. An approximation approach based upon the linear approximation of stress resultants is also applied to the optimization of laminated composites with multi-elements. (Author)