Japanese Aerospace Literature
This month: *Stress Analysis and Tests*

A95-45305 Stress analysis and optimum design for three-dimensional composite materials. A. YOKOYAMA (Mie Univ., Tsu, Japan), K. NAGAI (Mitsubishi Heavy Industries, Ltd., Nagoya Aerospace Systems Works, Japan), Z.-I. MAEKAWA, and H. HAMADA (Kyoto Inst. of Technology, Japan), *Materials challenge diversification and the future; Proceedings of the 40th International SAMPE Symposium and Exhibition*, Anaheim, CA, May 8–11, 1995. Book 1 (A95-45236 12-23), Covina, CA, Society for the Advancement of Material and Process Engineering (Science of Advanced Materials and Process Engineering Series. Vol. 40), 1995, pp. 892–902. 13 Refs. Documents available from Aeroplus Dispatch.

Three-dimensional fiber reinforced composite materials produced by impregnating the resin to the woven fabric are superior to the interlaminar strength, impact strength, and capability of forming complex shapes. They are also tailored materials, so we can obtain the required material properties by deciding the three-dimensional fiber construction appropriately. In this report, we propose an optimum design method for three-dimensional composite materials. Weight minimization problems subjected to the elastic moduli or the failure loads are considered. Strength analyses are performed using the stress averaging method which gives efficient calculation, and the genetic algorithm is applied in the optimization. Calculation is executed for the 5-axis woven CFRP three-dimensional composite, and the validity of the present design method is discussed. (Author)

A95-44919 Fracture toughness of structural ceramics under biaxial stress state by anticlastic bending test. T. ONO and M. KAJI (Kyocera Corp., Kagoshima, Japan), *ASME, International Gas Turbine and Aeroengine Congress & Exposition*, Houston, TX, June 5–8, 1995, p. 17. 18 Refs. Documents available from Aeroplus Dispatch.

Mixed-mode fracture of structural ceramics under biaxial stress state was investigated by an anticlastic bending test using the controlled surface flaw technique. The stress state of the anticlastic bending specimen is biaxial. This test enables the study of fractures under pure mode I, pure mode II, or any combination of mode I and mode II loading. To discuss the experimental results, a parameter 'T' was introduced to the modified maximum hoop stress criterion. This parameter represents frictional effects of crack interfaces on the mixed-mode fracture and can be obtained experimentally. Relative magnitudes of mode I and mode II stress intensity factors and the directions of non-coplanar crack extension angles were predicted using the parameter 'T'. Reasonable agreement with the experimental results was obtained. (Author)

A95-42220 Stress analysis of sandwich plate by the homogenization method. N. TAKANO, M. ZAKO (Osaka Univ., Japan), and N. KIKUCHI (Michigan, Univ., Ann Arbor), *Materials Science Research International* (ISSN 1341-1683), Vol. 1, No. 2, 1995, pp. 82–88. 11 Refs. Documents available from Aeroplus Dispatch.

An outline of the formulation of the homogenization method for the analysis of three-dimensional periodic elastic bodies is presented. The method has been shown to be effective for the analysis of composite materials since it was first introduced in the 1970s. However, since this method is applicable to periodic problems only, some engineering problems remain unsolved. For instance, the method cannot be applied to honeycomb sandwich plates and panels with reinforcing ribs, because these structures are not periodic in the thickness direction. In this paper, the application of the homogenization method to those composite structures is discussed. As a practical example, the stress analysis of a single-layered corrugated-core sandwich plate is presented. A method which homogenizes the complicated geometry to a simple solid model, obtains the homogenized material constants, and which calculates the microscopic stress is proposed.

A95-37973 Thermal stress analysis of thin plate bending of partially bonded dissimilar strips due to nonuniform change of temperature. N. NASEBE and M. A. M. SALAMA (Nagoya Inst. of Technology, Japan), *ICRS-4—Proceedings of the 4th International Conference on Residual Stresses*, Baltimore, MD, June 8–10, 1994 (A95-37926 10-39), Bethel, CT, Society for Experimental Mechanics, Inc., 1994, pp. 992–1001. 6 Refs. Documents available from Aeroplus Dispatch.

A solution to the problem of thin plate bending of partially bonded dissimilar strips due to the difference of temperature on the upper and the lower faces of the plates which does not include in-plane extension of the plates is obtained. The two strips are symmetrically bonded along a finite straight interface with debonding at both sides. The analysis is carried out using the complex stress function approach and the rational mapping function technique. Thermal stress distributions are obtained for arbitrary lengths of debonding, material constants, and rigidity ratios. The energy release rate of debonding is defined at the debonding tip. Expressions for the stress intensity of debonding (SID) at the debonding tips is derived in view of the energy release rate. Values of the SID are shown in graphs. (Author)

A95-37941 Measurement method of the stress distribution along a depth by polychromatic X-ray. J. SHIBANO, T. UKAI, and S. TADANO (Hokkaido Univ., Sapporo, Japan), *ICRS-4—Proceedings of the 4th International Conference on Residual Stresses*, Baltimore, MD, June 8–10, 1994 (A95-37926 10-39), Bethel, CT, Society for Experimental Mechanics, Inc., 1994, pp. 207–213. 6 Refs. Documents available from Aeroplus Dispatch.

In recent studies, the possible use of polychromatic mixed X-rays of different wavelengths has been proposed for another type of residual stress measurement. This paper presents a new polychromatic X-ray method for residual stress measurement. Since the relationship between the diffracted beam peak of the polychromatic X-ray and the strain along the depth direction could be confirmed from the tests by steel plates, the residual stress with the steep gradient along the depth direction in a subsurface layer was estimated by means of the formulas derived from this relation. (Author)

A95-35437 Influence of coating configuration on cyclic thermal shock fracture behavior of plasma sprayed coatings. M. FUKUMOTO (Toyohashi Univ. of Technology, Japan), T. YAMASAKI (Nippon Sharoy Seizo Co., Ltd., Japan), and I. OKANE (Toyohashi Univ. of Technology, Japan), *FGM 94; Proceedings of the 3rd International Symposium on Structural and Functional Gradient Materials*, Swiss Federal Inst. of Technology, Lausanne, Switzerland, Oct. 10–12, 1994 (A95-35401 09-23), Lausanne, Switzerland, Presses Polytechniques et Universitaires Romandes, 1995, pp. 425–432. 5 Refs. Documents available from Aeroplus Dispatch.

Evaluation of the thermal shock fracture behaviors of plasma-sprayed ceramic coatings is one of the essential problems to be solved to obtain the necessary reliability of such coatings for superior heat protection. Though many types of rectangular specimens have been used for thermal shock evaluation, the properties have not always been evaluated correctly because the fracture behavior of these rectangular specimens is strongly affected by the preferential oxidation-induced cracks at the corners of the specimens. More precise evaluation can be anticipated by a disk-shaped specimen, as the preferential fracture due to the specimen's morphology must be inhibited in such a specimen. In the present study, disk-shaped duplex and functionally graded ZrO_2/NiCrAlY coating specimens were prepared by plasma spraying, and the cyclic thermal shock fracture behaviors of the disk-shaped specimens, as well as the effect of the coating configuration on the fracture behavior, were evaluated. Unsteady thermal stress analyses by FEM of the cooling processes of thermal shock cycles were also conducted. (Author)

A95-35433 Thermal shock fracture mechanism of functionally gradient materials as studied by burner heating test. A. KAWASAKI and R. WATANABE (Tohoku Univ., Sendai, Japan), *FGM 94; Proceedings of the 3rd International Symposium on Structural and Functional Gradient Materials*, Swiss Federal Inst. of Technology, Lausanne, Switzerland, Oct. 10–12, 1994 (A95-35401 09-23), Lausanne, Switzerland, Presses Polytechniques et Universitaires Romandes, 1995, pp. 397–404. 11 Refs. Documents available from Aeroplus Dispatch.

The thermomechanical properties of metal/ceramic functionally gradient materials were evaluated by a burner heating test using an H_2/O_2 combustion flame, which simulated the environment of the heated inner wall of a rocket combustor. Disk-shaped graded samples were used for the test in which the ceramic surface of the sample was heated with the burner flame, and the back surface was cooled with flowing water. The critical temperature of the first crack formation, which was always observed on the ceramic surface during cooling, was determined in the test. The stress distributions in the sample during heating and cooling cycles, calculated by the finite element method, shows the generation of large compressive and tensile stresses during heating and cooling, respectively, which was attributed to the non-elastic deformation of the heated sample surface due to an excess in the compressive stress. The fracture mechanism, in terms of crack formation and spalling in the FGMs, was discussed on the basis of the stress distributions in addition to the fracture mechanics approach. (Author)

A95-26749 Thermal stress analysis for Al honeycomb sandwich plates with very thin CFRP faces. N. WATANABE and K. TERANISHI (Tokyo Metropolitan Univ. of Technology, Japan), *36th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, and *AIAA/ASME Adaptive Structures Forum*, New Orleans, LA, April 10–13, 1995, Technical Papers. Pt. 3 (A95-26551 06-39), Washington, DC, American Inst. of Aeronautics and Astronautics, 1995, pp. 1955–1963. 12 Refs. Documents available from Aeroplus Dispatch.

The thermal stress in sandwich plates composed of very thin CFRP face and Al honeycomb core may often cause a thermal buckling of the face coincident with the periodic pattern of the core. By using our extended homogenization method and the exact honeycomb core model, the magnitude and distribution of the thermal stress are examined and its characteristic is revealed. Next, buckling and post-buckling analyses of the hexagonal laminate with the residual thermal stress are carried out numerically and buckling characteristics are examined. From these analyses it is proved that the most effective term should be the in-plane rigidity of the core and that the lamination or stiffness of the face should have a little less effect. For such sandwich plates, the thermal buckling is expected to occur by the present analysis, and these results are generally coincident with the actual examples. Therefore, the present analysis is considered to be sufficiently effective and accurate. (Author)

A94-28201 Fatigue crack closure and its related problems. M. JONO (Osaka Univ., Suita, Japan), *Computational and experimental fracture mechanics—Developments in Japan* (A94-28194 09-39), Southampton,

United Kingdom and Boston, MA, Computational Mechanics Publications, 1994, pp. 317–345. 24 Refs. Documents available from Aeroplus Dispatch.

Fatigue crack closure and growth behavior characteristics related with crack closure were summarized based on the experimental results obtained in the author's laboratory. Emphasis was put on the significance of measuring technique of crack closure with good accuracy, and refinement of unloading elastic compliance method was reviewed. The fatigue crack growth mechanism and crack opening ratio were discussed as a function of the effective stress intensity range, which resulted in the trilinear form of crack growth rate curve in so-called region II of growth rate. Higher crack growth rates in mechanically short fatigue cracks than in conventional long fatigue cracks were successfully explained by the crack closure concept. Furthermore, fatigue crack growth rates under variable amplitude loadings were extensively investigated in conjunction with crack closure behavior, and an estimation method of fatigue crack growth rates under variable amplitude loadings was expressed in terms of the effective stress intensity range. (Author)

A94-28200 Fracture mechanics of small cracks in metals, ceramics and composites. K. TANAKA, Y. AKININWA, and H. TANAKA (Nagoya Univ., Japan), *Computational and experimental fracture mechanics—Developments in Japan* (A94-28194 09-39), Southampton, United Kingdom and Boston, MA, Computational Mechanics Publications, 1994, pp. 291–315. 24 Refs. Documents available from Aeroplus Dispatch.

Mechanical approaches to small cracks in fatigue and fracture are first described, and then applied to the growth behavior of small cracks in metals, ceramics, and composites. Physically small cracks having lengths less than a few millimeters can be classified into three categories. Cracks whose length is on the order of grain size are microstructurally small cracks. Cracks which grow following the fracture mechanics law obtained from the standard fracture mechanics tests are called large cracks. Cracks of intermediate length are mechanically small cracks. Acceleration of the propagation of mechanically small cracks is caused by a small amount of crack-tip shielding due to the crack wake such as crack closure and fiber bridging. The SIF value at the crack tip is shown to be the controlling parameter for the growth of mechanically small cracks under monotonic and cyclic loading. For microstructurally small cracks, a local parameter including the microstructural effect is necessary. (Author)

A94-28196 Dynamic crack problems. S. AOKI (Tokyo Inst. of Technology, Japan), *Computational and experimental fracture mechanics—Developments in Japan* (A94-28194 09-39), Southampton, United Kingdom and Boston, MA, Computational Mechanics Publications, 1994, pp. 111–137. 48 Refs. Documents available from Aeroplus Dispatch.

Some topics in the recent studies of dynamic crack problems were presented. These are about 1) a new instrumentation system developed for determining the impact fracture toughness of ceramics or ceramic-reinforced metals at elevated temperatures up to 1200 C, 2) simple formulas introduced to determine the dynamic stress intensity factor of one-point-bend or three-point-bend specimens from the measured time history of impact force, 3) a numerical simulation of caustic method, which was carried out to investigate the dependence of impact fracture toughness on the loading rate and the effect of acceleration on the crack propagation toughness, and 4) a new method using the conventional finite element elements and a finite domain integral for determining the dynamic stress intensity factor for a rapidly propagating crack not only in a linear elastic but also in a viscoelastic solid. (Author)

A94-28195 Body force method and its application. H. NISITANI (Kyushu Univ., Fukuoka, Japan) and D. H. CHEN (Kyushu Inst. of Technology, Iizuka, Japan), *Computational and experimental fracture mechanics—Developments in Japan* (A94-28194 09-39), Southampton, United Kingdom and Boston, MA, Computational Mechanics Publications, 1994, pp. 1–60. 44 Refs. Documents available from Aeroplus Dispatch.

The principle of the body force method (BFM) is illustrated and the most general formula based on the principle of superposition is proposed. The relationship between the BFM and the BEM is discussed. The extension of the BFM and thermoelastic problems is explained.

A94-28101 Two-dimensional stress analysis and strength of band adhesive butt joints of dissimilar adherends subjected to external bending moments. K. TEMMA (Kisarazu National College of Technology, Japan), T. SAWA (Yamanashi Univ., Kofu, Japan), T. NISHIGAYA (Shizuoka Prefecture Police, Japan), and H. UCHIDA (Kisarazu National College of Technology, Japan), *JSME International Journal, Series A* (ISSN 0914-8809), Vol. 37, No. 3, 1994, pp. 246–254. 17 Refs. Documents available from Aeroplus Dispatch.

The stresses of band adhesive butt joints, in which the interfaces were partially bonded, were analyzed using a two-dimensional theory of elasticity to establish the fracture criteria when the joints of dissimilar adherends were subjected to external bending moments. In the analysis, the dissimilar adherends and the adhesive were replaced with finite strips when the interfaces were bonded by the adhesive at two regions. In the numerical calculations, the effect of the ratios of Young's moduli between adherends and the adhesive, the thickness of the adhesive, the bonding area and the position on the stress distributions at the interfaces were demonstrated. As a result, it was seen that band adhesive joints were available when the bonding area and positions were determined taking into account the external load distributions. Experiments were performed on the strains of adherends and the joint strength. Analytical results were consistent with the experimental ones.

A94-28100 Two-dimensional thermal stress analysis of butt adhesive joint containing rigid fillers in the adhesive. F. NAKAGAWA (Tokyo Metropolitan College of Aeronautical Engineering, Japan), Y. NAKANO (Shonan Inst. of Technology, Fujisawa, Japan), and T. SAWA (Yamanashi Univ., Kofu, Japan), *JSME International Journal, Series A* (ISSN 0914-8809), Vol. 37, No. 3, 1994, pp. 238–245. 17 Refs. Documents available from Aeroplus Dispatch.

Thermal stress distribution and thermal strength were examined when butt adhesive joints with rigid fillers in the adhesive were in steady state temperature distribution. In the analyses, thermal stress distribution in the adhesive was obtained using the two-dimensional theory of elasticity in the case where adherends of the same size and rigid material were kept at a constant temperature and the side surfaces of the joint were surrounded with fluid of a different constant temperature. Numerical calculations showed that thermal stress was tensile near the edges of the interface between the adherend and the adhesive layer, that around the interface area underneath which the filler was located, the thermal stress was concentrated at the periphery of the filler, and that a large amount of thermal stress was generated when the filler size was large. Photoelastic experiments were carried out, and the analytical results were shown to be consistent with the experimental ones.

A95-11780 Three-dimensional thermal stress analysis under steady state with heat generation by boundary element method. Y. OCHIAI (Kinki Univ., Higashi Osaka, Japan), *JSME International Journal, Series A: Mechanics and Material Engineering* (ISSN 1340-8046), Vol. 37, No. 4, 1994, pp. 355–359. 5 Refs. Documents available from Aeroplus Dispatch.

The BEM does not require a domain integral in steady-state thermoelastic problems without heat generation. However, with heat generation, the domain integral is necessary. This paper shows that the three-dimensional problem of steady state thermoelasticity with nonuniform heat generation can be easily solved without a domain integral by means of the BEM. This method can also be applied to steady state thermal stress problems under generally complicated heat generation. However, in this case, the domain must be divided into small areas where distributions of heat generation satisfy the Laplace equation. (Author)

A95-11779 Constitutive equation for cyclic plasticity considering memorization of back stress. H. ISHIKAWA, K. SASAKI (Hokkaido Univ., Sapporo, Japan), and T. NAKAGAWA (Mitsubishi Electric Corp., Kamakura, Japan), *JSME International Journal, Series A: Mechanics and Material Engineering* (ISSN 1340-8046), Vol. 37, No. 4, 1994, pp. 347–354. 13 Refs. Documents available from Aeroplus Dispatch.

One of the difficult problems in the study of the constitutive equation for cyclic plasticity is the prediction of ratchetting behavior that is induced by the superposition of a cyclic secondary load to a constant primary load in a biaxial case, or by the mean stress in a uniaxial case. This paper shows the constitutive equation in which the memorization of the back stress is considered for ratchetting behavior, especially for biaxial ratchetting behavior. To verify the applicability of the constitutive equation to ratchetting behavior, a biaxial ratchetting test was carried out using SUS 304 stainless steel at room temperature. As a result, it was found that the simulations based on the constitutive equation have good agreement with the tests. (Author)

A95-11777 A two-dimensional piezothermoelastic problem in an orthotropic plate exhibiting crystal class mm2. F. ASHIDA (Tsuyama National College of Technology, Japan), N. NODA (Shizuoka Univ., Japan), T. TAUCHERT, and R. THEODORE (Kentucky, Univ., Lexington), *JSME International Journal, Series A: Mechanics and Material Engineering* (ISSN 1340-8046), Vol. 37, No. 4, 1994, pp. 334–340. 21 Refs. Documents available from Aeroplus Dispatch.

A solution technique for two-dimensional piezothermoelastic problems in orthotropic solids of crystal class mm2 is proposed. The solution technique is formulated in terms of two piezothermoelastic potential functions, three piezoelastic potential functions, and a single piezoelectric potential function. Next, by using the solution technique, a two-dimensional piezothermoelastic problem in an orthotropic thin plate of crystal class sq mm which is subjected to heating on one surface and electric surface charge on both surfaces is analyzed. The numerical calculations are carried out for cadmium selenide exhibiting class mm2 symmetry. The elastic displacements and stresses are compared with those obtained for a similar thermoelastic problem without the piezoeffect. The effects of the electric surface charge on the elastic displacements, stresses, electric potential, electric field intensities, and electric displacements are also investigated. (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 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)