Japanese Aerospace Literature This month: *Fracture Mechanics*

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 and Exposition*, Houston, TX, June 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 modes I and 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 modes I and 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)

A95-44484 Mechanical properties of metallic composites. S. OCHIAI ed. (Kyoto Univ., Japan), *Materials Engineering*, New York, Marcel Dekker, Inc., Vol. 7, 1994, p. 819 (For individual items see A95-44485–A95-44506). Documents available from Aeroplus Dispatch.

The present volume discusses the structure, fatigue, thermophysical and elastic properties of oxide dispersion-strengthened (ODS) alloys, the creep and fracture of dispersion-strengthened materials, the threshold stresses and creep of dispersion-strengthened materials, ODS alloys' oxidation and corrosion behavior, Cu-based alloys, ODS ferritic alloys, and Ni- and Pt-based DSOs. Also discussed are fiber and matrix alloy materials for metal-matrix composites (MMCs), the strength of unnotched composites, the fracture mechanics of MMCs, MMC high temperature mechanical behavior, the mechanical properties of eutectic composites, MMC wear resistance, interfaces in fiber and whisker reinforced alloys, and MMC fabrication methods and applications.

A95-42799 Postbuckling strength of composite stiffened panel under shear load. T. TAKI and T. KITAGAWA (Kawasaki Heavy Industries, Ltd., Kakamigahara, Japan), *AIAA, 1st Aircraft Engineering, Technology, and Operations Congress*, Los Angeles, CA, 1995, p. 10. 15 Refs. Documents available from Aeroplus Dispatch.

The purpose of this study is to establish a methodology for predicting the failure load of a composite stiffened panel under shear loading. An experimental and an analytical investigation are conducted. A simple strip analysis is proposed to estimate the stress condition around the stiffener/skin-bonded area after skin buckling. Fracture mechanics is applied to the stiffener/skin disbond which is one of the predominant failure modes of composite stiffened panels. Stiffened panels made of graphite/epoxy are tested under shear loading. The correlation between the predicted failure loads and those of the experimental results is good. (Author)

A95-37936 Evaluation of fracture mechanism of ceramic-metal joint by ultrasonic method. Y. ARAI and E. TSUCHIDA (Saitama Univ., Urawa, Japan), *ICRS-4—Proceedings of the 4th International Conference on Residual Stresses*, Baltimore, MD, 1994 (A95-37926 10-39), Bethel, CT, Society for Experimental Mechanics, Inc., 1994, pp. 122–131. 10 Refs. Documents available from Aeroplus Dispatch.

Fracture initiation and stable crack extension on the interface were measured by the ultrasonic method for the Si_3N_4-carbon steel joints. Based on the results, the fracture mechanisms of the ceramic-metal joints were studied. Analytical studies on the joining residual stresses for the Si_3N_4 carbon steel joint specimen were performed by the FEM. It is found that the fracture initiation and the stable crack extension on the interface can be measured by the ultrasonic method. The ultrasonic echo height increases with the fracture initiation. The stable crack extension can be also estimated through the ultrasonic echo height. The fracture initiation occurs before the maximum load at the ceramic-interlayer interface. The interface cracks grow stably on the interface before the final fracture. The strength of the ceramic-metal joints are given by the nominal bending stress at the final fracture. The strength of the ceramic-metal joints are controlled by the characteristics of the interface crack growth. The final fracture occurs when the interface crack deflects into the ceramic. Using applied and residual stress intensity factor for the interface crack and the stress distribution around the interface crack, the final fracture can be successfully predicted. (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, 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 nonelastic 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)

A95-35103 Fracture analysis of mullite ceramics using acoustic emission technique. Y. YAMADE, Y. KAWAGUCHI (Sumitomo Metal Industries, Ltd., Amagasaki, Japan), N. TAKEDA, and T. KISHI (Tokyo, Univ., Japan), *Journal of Acoustic Emission* (ISSN 0730-0050), Vol. 12, Nos. 3–4, 1994, pp. 127–140. 15 Refs. Documents available from Aeroplus Dispatch.

The detection of the microcrack initiation and extension is necessary for the analysis of fracture mechanism of ceramics. Acoustic emission (AE) technique was applied to detect the micro-crack initiation and extension in mullite ceramics during mechanical tests. The crack extension from natural defects prior to final failure was detected clearly during four-point bending. The discrimination between the AE signal and noise, and the two-channel locational detection can be achieved with the direct observation of AE waveforms. The crack extension behavior was also observed using chevron-notched beam bending tests with two-channel AE measurements. To measure the transition point from stable to unstable crack growth, it is necessary to detect the correct fracture toughness of the chevron notch test. Cumulative AE energy showed a qualitative agreement with the crack velocity calculated from the change in crack opening displacement. The AE measurement can be used for the K(Ic) evaluation. (Author)

A95-31353 Fracture behavior of silicon nitride at elevated temperatures. M. MATSUI and M. MASUDA (NGK Insulators, Ltd., Nagoya, Japan), *Tailoring of mechanical properties of Si_3N_4 ceramics, Proceedings of the NATO Advanced Research Workshop on Tailoring of High Temperature Properties of Si_3N_4 Ceramics*, Munich, Germany, 1993 (A95-31326 08-27), Dordrecht, Netherlands, Kluwer Academic Publishers (NATO ASI Series. Vol. E 276), 1994, pp. 403–414. 11 Refs. Documents available from Aeroplus Dispatch.

Static and cyclic fatigue tests were carried out under tensile stress to clarify slow crack growth behavior and creep behavior for silicon nitride at elevated temperatures. The static fatigue mechanism was classified into slow crack growth of preexisting flaws or creep deformation, depending on the temperature and the applied stress. In the slow crack growth realm, the strength degradation was controlled by the power law for crack growth rate. In the creep deformation realm, the modified Larson–Miller parameter was applicable to the life prediction under static stress. At elevated temperatures, the cyclic fatigue strongly depends on the frequency, the lower the frequency, the less the fatigue resistance. A failure diagram was constructed to show the effects of mean stress and stress amplitude on fatigue strength. It was concluded that a design methodology proposed for metal fatigue is applicable to the sintered silicon nitride examined at elevated temperatures. (Author)

A95-31348 Tensile creep rupture and subcritical crack growth of silicon nitride. T. OHJI (Government Industrial Research Inst., Nagoya, Japan), *Tailoring of mechanical properties of Si_3N_4 ceramics, Proceedings of the NATO Advanced Research Workshop on Tailoring of High Temperature Properties of Si_3N_4 Ceramics*, Munich, Germany, 1993 (A95-31326 08-27), Dordrecht, Netherlands, Kluwer Academic Publishers (NATO ASI Series. Vol. E 276), 1994, pp. 339–351. 26 Refs. Documents available from Aeroplus Dispatch.

There are two regions in a fracture mechanism map of silicon nitride at temperatures higher than 1200 C: slow crack growth failure and creep damage rupture. This study intends to clarify the difference between these two fracture mechanisms in terms of creep behaviors, microstructural changes, fatigue life properties and fracture surfaces. Two grades of silicon nitrides were used. One is hot-pressed silicon nitride which contains a continuous glassy phase at the interfaces, and the other is HIP-ed silicon nitride with a discontinuous glassy phase. It was demonstrated that the transition from the slow crack growth fracture regime to the creep damage rupture one occurred when the applied stress decreases to a range of 200–250 MPa for both materials. (Author)

A95-24222 Mechanical fatigue of epoxy resin. M. NAGASAWA, H. KINUHATA, H. KOIZUKA, K. MIYAMOTO, T. TANAKA, H. KISHIMOTO (Toyota Technological Inst., Nagoya, Japan), and T. KOIKE (Yuka Shell Epoxy Co., Ltd., Yokkaichi, Japan), *Journal of Materials Science* (ISSN 0022-2461), Vol. 30, No. 5, 1995, pp. 1266–1272. 13 Refs. Documents available from Aeroplus Dispatch.

In static bending fatigue tests, epoxy resins show practically no fatigue if the stress given to specimen is lower than a critical value, which is close to the bending strength of the specimen. In cyclic bending fatigue tests, on the other hand, the resins are easily fractured even though the stresses are far below the critical values. Some strain may be accumulated on the surface of specimen through cyclic deformations. However, the strain accumulated is reversible. If the specimen is allowed to rest, the strain disappears. If the strain reaches a critical value, an irreversible transition may be induced, probably in

the arrangement of segments on the surface. A crack nucleus thus created may propagate and cause the final fracture of the specimen, following the fracture mechanics of elastic materials. The lifetime of epoxy resins under cyclic bending load is determined by the time required for creating a crack nucleus on surface. (Author)

A95-20868 Nonlinear fracture mechanics analysis of end notched flexure specimen with tough interlayer. K. ESAKI, I. KIMPARA, K. KAGEYAMA, T. SUZUKI, and I. OHSAWA (Tokyo, Univ., Japan), *9th American Society for Composites, Technical Conference*, Univ. of Delaware, Newark, 1994, Proceedings (A95-20803 04-24), Lancaster, PA, Technomic Publishing Co., Inc., 1994, pp. 621–628. 13 Refs. Documents available from Aeroplus Dispatch.

An elastic-plastic analysis of the end notched flexure (ENF) specimen with tough interlayer is conducted by two-dimensional finite element modeling. Interlayer refers to a mixture of thermoplastic particles and thermoset base resin, selectively localized between laminae as a thin resin film. It is observed experimentally that plastic deformation in the interlayer has direct effect upon the interlaminar delamination growth and the toughness. The purpose of study is to evaluate Mode II interlaminar fracture toughness of interlayer-toughened composites with fracture mechanics parameter, J-integral, which is applicable to elastic-plastic regime. Effect of the material nonlinearity on the load vs crack shear displacement (CSD) diagram and J-integral is examined and limitation of linear elastic fracture mechanics approach to the tough composites is discussed. (Author)

A94-28203 Fully plastic solutions of three-dimensional cracks—A comparison. G. YAGAWA, S. YOSHIMURA, and C.-R. PYO (Tokyo, 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. 91–109. 38 Refs. Documents available from Aeroplus Dispatch.

Two finite element algorithms for three-dimensional fully plastic solutions of cracks—1) the algorithm based on the penalty function method and Uzawa's algorithm and 2) the mixed finite element algorithm with the fractional step method—are reviewed. It is shown through comparison between the three-dimensional fully plastic solutions of a center cracked plate obtained by both approaches that the second approach ives accurate solutions. Since the second approach has potential for treating a large-scale finite element equation system without any numerical instability, it will be applied to practical cracked structures such as surface cracked cylinders and elbows.

A94-28202 Boundary element method and its applications to the analyses of dissimilar materials and interface cracks. R. YUUKI and J.-Q. XU (Tokyo, 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. 61–90. 35 Refs. Documents available from Aeroplus Dispatch.

To evaluate the strength of dissimilar materials such as adhesive joints and metal/ceramics bonded joints, the stresses on the interface or the stress intensity factors for an interface crack must be analyzed accurately and efficiently. The boundary element method seems to be the most useful and powerful tool for the elastostatic analysis of dissimilar materials or interface crack problems. In this paper, the boundary element analysis system developed especially for the analysis of interface problems is introduced. Some applications to the analyses of adhesive joints, metal/ceramics bonded joints, and interface cracks are presented. (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)

A94-28199 General singular stress field in fracture mechanics. 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. 213–262. 25 Refs. Documents available from Aeroplus Dispatch.

The paper presents a method of analysis of stress singularity in which the complex function expression used by Theocaris (1974) is combined with the technique presented by Dempsey and Sinclair (1979) for reducing the order of coefficient matrix by 4. A method of numerical analysis, called the body force method, for the intensity analysis is briefly illustrated. These two methods are used to analyze the problem of bimaterial close or open edge and the problem of a crack meeting an interface.

A94-28197 Inverse problems in fracture mechanics. S. KUBO (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. 139–163. 51 Refs. Documents available from Aeroplus Dispatch.

A brief review of inverse problems is given, and inverse problems are classified into domain/boundary inverse problems, governing equation inverse problems, initial value/boundary value inverse problems, force/source inverse problems, and material properties inverse problems. Examples of inverse problems in fracture mechanics are provided. The identification of a crack embedded in a body from electrical potential distribution observed on the surface of the body is described. The electric potential computed tomography method proposed for crack identification by applying boundary-element-based inverse analysis schemes is described. An estimation of initial residual stress fields from residual stresses redistributed due to crack initiation and propagation is demonstrated.

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)

A94-28194 Computational and experimental fracture mechanics—Developments in Japan. H. NISITANI, ed. (Kyushu Univ., Fukuoka, Japan), *Topics in Engineering*, Southampton, United Kingdom and Boston, MA, Computational Mechanics Publications, Vol. 16, 1994, p. 446. (For individual items see A94-28195–A94-28203.) Documents available from Aeroplus Dispatch.

Two adaptive schemes for controlling the end-effector impedance of dexterous manipulators are described. Each control system consists of two subsystems: a simple 'filter' which characterizes the desired dynamic relationship between the end-effector position and the environmental contact force and modifies the reference trajectory according to this relationship, and an adaptive controller which produces the control input required to track this modified trajectory. The proposed controllers are very general and computationally efficient since they do not require knowledge of either the mathematical model or the parameter values of the robot dynamics of the environment, and are implemented without calculation of the robot inverse kinematic transformation. It is shown that control strategies are globally stable in the presence of bounded disturbances, and the size of the tracking errors can be made arbitrarily small. It is also shown that the impedance controllers can be modified to provide accurate force regulation in the presence of uncertainty regarding the location and stiffness of the environment.

A95-11785 Mesoscopic simulation of microcracking behaviors of brittle polycrystalline solids. I—Study of isotropic theory in continuum damage mechanics. II—Study of anisotropic theory in continuum damage me. Y. TOI and J.-S. CHE (Tokyo, Univ., Japan), *JSME International Journal, Series A: Mechanics and Material Engineering* (ISSN 1340-8046), Vol. 37, No. 4, 1994, pp. 434–441. 18 Refs. Documents available from Aeroplus Dispatch.

A mesoscopic simulation method at grain scale using a discontinuum mechanics model is employed to obtain data on microcraking and reduced elastic compliances of microcracked solids. The validity and limitations of the isotropic theory of continuum damage mechanics are studied. It is shown that the existing anisotropic theory is inapplicable to the compression-dominant stress state because of an associated type of damage evolution equation, although it is effective in the tensile stress field.