Japanese Aerospace Literature This month: *Fracture Mechanics*

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, March 1, 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), *In American Society for Composites*, Technical Conference, 9th, Univ. of Delaware, Newark, Sept. 20–22, 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 2D 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 versus 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)

A94-28235 Effects of fracture origin and microstructure on bending strength of high-strength Si_3N_4. A. YAMAKAWA, T. YAMAMOTO, T. AWAZU, K. MATSUNUMA, and T. NISHIOKA (Sumitomo Electric Industries, Ltd., Itami, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 489, June 1994, pp. 599–605. In Japanese. 13 Refs. Documents available from Aeroplus Dispatch.

The effects of fracture origin and microstructure on bending strength have been investigated with four kinds of Si_3N_4 ceramics. The mean grain sizes of three kinds of Si_3N_4 ceramics were 0.2 micron and the other one was 0.4 micron. The average bending strength of the weakest one was 1000 MPa and the strongest one was 1500 MPa. Three kinds of defects, pores, anomalously grown grains and inclusions (Fe) were identified as fracture origins. The stresses applied at these fracture origins were calculated from the bending strength and the locations of fracture origins. As the parameter to describe the size of fracture origin, the equivalent crack length was estimated. The strength of the high-strength SiN, ceramics with more than 1500 MPa depended on both the grain size and the defect size same as conventional-strength Si_3N_4 and agreed with the Kishimoto's equation, from which the fracture strength could be estimated by using defect size, grain size, and fracture toughness. (Author)

A94-28203 Fully plastic solutions of three-dimensional cracks—A comparison. G. YAGAWA, S. YOSHIMURA, and C.-R. PYO (Tokyo, Univ., Japan), *In 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 3D 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 3D fully plastic solutions of a center cracked plate obtained by both approa ches that the second approach gives 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), *In 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), *In 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), *In 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), *In 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), *In 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), *In 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 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), Southampton, United Kingdom and Boston, MA, Computational Mechanics Publications (Topics in Engineering, Vol. 16), 1994, p. 446 (For individual items see A94-28195 to 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.

A95-16622 Relationship between fracture toughness and second phase particles in extruded high strength Al-Zn-Mg-Cu-La system alloys with high stress corrosion cracking resistance. Y. KISHI (Nippon Inst. of Technology, Miyashiro, Japan), Y. HIROSE, (Kanazawa Univ., Japan), I. TSUKUDA, S. NAGAI (Showa Aluminum Corp., Sakai, Japan), and K. HIGASHI (Osaka Prefecture, Univ., Sakai, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 495, Dec. 1994, pp. 1571–1577. In Japanese. 13 Refs. Documents available from Aeroplus Dispatch.

Extruded Al-8 wt. pct Zn-1 to around 2.5 wt. pct Mg-1.2 wt. pct Cu-4 wt. pct La alloys with high tensile strength and good stress corrosion cracking resistance were developed, and their fracture toughness was investigated. The effect of metallurgical parameters on the fracture toughness value was examined. The main results are: (1) The fracture toughness values of the alloy, which were about 20 MPa sq-rt m without anisotropy, were not influenced by Mg content. (2) The second-phase particles in the extruded alloys, Zn and La, had mean diameters of about 4.7 microns, and the volume fraction of the particles was 1.6 to around 2.3 vol. pct. (3) The Zn and La second-phase particles in the extruded alloys cracked easily and became the nucleus of voids when the matrix fractured. The fracture toughness of the extruded alloys was affected by the particles, and an equation is presented showing its relation to the volume fraction and the mean diameter of the second-phase particles.

A95-15589 Fracture morphology of high strength steel fiber reinforced metal matrix composite produced by explosive molding method. M. NISHIDA, K. MINAKUCHI, T. ARAKI (Ehime Univ., Matsuyama, Japan), R.-I. AGAWA (Sumitomo Heavy Industries, Ltd., Niihama, Japan), and K. HYOUDOU (Tokusen Kogyo Co., Ltd., Ono, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 493, Oct. 1994, pp 1315–320. In Japanese. 7 Refs. Documents available from Aeroplus Dispatch.

Fiber reinforced metal matrix composite materials which consist of high-strength ductile steel wire and aluminum or titanium foil sheets were produced by an explosive bonding method. Strength property was evaluated by a tensile test. For the Al-matrix composite, the tensile strength was 80 percent of the value predicted by the law of mixture and fracture initiated at the weakly bonded area between the fiber and the matrix. For the Ti-matrix composite, the tensile strength was in agreement with the value predicted by the law of mixture and fracture initiated at the originally fused interface between the sheets. A cup and cone type of fracture was observed in the fiber of the Al-matrix composite, and a cup and cone and shear type of fracture were observed in the fiber of the Ti-matrix composite. (Author)

A95-15588 New development of laser speckle strain/displacement gage for the measurement of fracture mechanics parameters. I. NISHIKAWA, K. OGURA (Osaka Univ., Toyonaka, Japan), M. YAMAGAMI (Gunze, Ltd., Moriyama, Japan), and K. KUWAYAMA (Horiba, Ltd., Kyoto, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 493, Oct. 1994, pp. 1290–1296. In Japanese. 17 Refs. Documents available from Aeroplus Dispatch.

The paper describes a new strain/displacement measuring SSDG system by using laser speckles. Emphasis was put on the development of a real time noncontact system which could be applicable to the measurements of a local strain and a crack opening displacement (COD) around crack tips both at room- and elevated temperatures. A conventional double sensor SSDG system, in which two image sensors are required to eliminate the rigid motion of samples, is discussed. A single sensor SSDG system was newly proposed which was applicable to the COD measurements. A real time processing of speckle movements was realized by an originally developed software. The applicability of the single sensor system was successfully tested in the COD measurements of cracks in ceramics and in the closure measurements of small cracks in steels under cyclic thermal stressing at elevated temperatures. An application of this system to a crack tip deformation measurement under mixed loading of Mode I and II is described. (Author)

A95-15587 Development of a simplified J-estimation scheme based on the reference stress method. S. TAKAMATSU (Kawasaki Heavy Industries, Ltd., Tokyo, Japan) and T. SHIMAKAWA (Central Research Inst. of Electric Power Industry, Komae, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 493, Oct. 1994, pp. 1284–1289. In Japanese. 10 Refs. Documents available from Aeroplus Dispatch.

J-integral is a feasible parameter to represent fracture behavior in the nonlinear regime. However, there are many difficulties in calculating an accurate value of J-integral in actual components. Some simplified methods have been proposed to estimate the J-integral, and applicability of these methods has been recognized. Although J-estimation scheme based on the reference stress method has the advantage of being applicable to many problems, the method has not been established yet. This paper presents a detailed procedure and applications for ductile fracture, creep fatigue, inhomogeneous and three-dimensional problems. (Author)

A95-15581 Effect of static stress on foreign object damage of ceramics. S. HAMADA, G. IYOGI, and T. TERAMAE (Tokyo Electric Power Co., Chofu, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 493, Oct. 1994, pp. 1195–1199. In Japanese. 12 Refs. Documents available from Aeroplus Dispatch.

Impact tests were performed to evaluate the effect of static initial stress field on the foreign object damage of ceramics, using steel and Si_3N_4 balls as the projectiles, and five kinds of SiC and Si_3N_4 ceramics as target specimens of $7.5 \times 10 \times 85$ mm size. After the impact, three point bending tests were carried out to evaluate the residual strength of the specimens, and the difference in failure with ball contact was discussed taking into consideration the results of numerical analyses. From the impact tests, the critical condition to produce the effect of initial stress on foreign object damage became clear. The numerical impact fracture analyses indicated that the effect of residual tensile stress is caused by an increase in compressive permanent deformation in the target at impact, due to the initially applied static load. It was also found that the mechanical property of the target material subjected to compressive load is an important parameter in evaluation of the impact damage of Si_3N_4 ceramics. (Author)

A95-15580 Review of fracture mechanics for aircraft structures. G. FUJIWARA (Japan Airlines Co., Ltd., Tokyo), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 493, Oct. 1994, pp. 1188–1194. In Japanese. 12 Refs. Documents available from Aeroplus Dispatch.

Well over 32 percent of the commercial air carrier fleet, worldwide, are beyond their original 20-year design life goal, and by the turn of the century, 64 percent of the current fleet will be at least 20 years old. This is because economic and market conditions have resulted in the use of commercial jet airplanes beyond their original economic design life objectives. As aircraft exceed their economic design life objectives, the incidence of fatigue increases and corrosion may become more widespread. The purpose of this paper is to discuss our experience with aging aircraft, the basic considerations of fracture mechanics treatment of cracks initiating at rivet holes (i.e., multiple-site damage), and some problems due to fatigue cracks in aircraft components from the operators viewpoint. (Author)

A95-14898 Temperature effect on deformation and fracture behaviors of ZrOz/Ni composite materials. T. OGAWA, K. ARAKAWA, K. TAKAHASHI, H. TAKEBE, and K. MORINAGA (Kyushu Univ., Kasuga, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 494, Nov. 1994, pp. 1463–1468. In Japanese. 7 Refs. Documents available from Aeroplus Dispatch.

Zirconia-nickel composite materials were fabricated by powder processing technique and pressureless sintering. A tensile testing machine with a scanning electron microscope was utilized to study the deformation and fracture behaviors of the materials. Tensile tests were performed on dumbbell type specimens in vacuum at temperatures up to 800 C. Stress-strain relationships were determined for the composites as functions of temperature and volume fraction of ZrO_2. The result showed that both the tensile strength and elongation to fracture decreased as the test temperature increased. It was also found that the strength increased with increasing volume fraction of ZrO_2 up to 50 percent. To understand such effects, the deformation and fracture behaviors were investigated from microscopic viewpoints through in situ observation of the specimen surface and the fracture surface examination. (Author)

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, Oct. 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.