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characterized by grain boundary fracture occuring along carbide and carbonitride inclusions and aluminum-rich zones. The embrittlement of VT5 alloy is attributed to aluminum redistribution within the grains during

heat and thermomechanical treatments, which leads to the formation of clusters of a solid solution based on Ti(x)Al (where x is equal to or less than 1); the number of the clusters depends on the aluminum content of the alloy.

Japanese Aerospace Literature
This month: *Structural Mechanics*

A88-24553   Post-buckling behavior of centrally cracked plates under tension TAKASHI FUJIMOTO and SEINOSUKE SUMI, *JSME International Journal* (ISSN 0913-185X), Vol. 30, Nov. 1987, pp. 1714-1723. 23 Refs.

The postbuckling behavior of centrally cracked rectangular plates subjected to uniaxial tension is analyzed using the FEM, taking into account both geometrical and material nonlinearities. The FEM formulation is based on the total Lagrangian coordinate system and the flow theory of plasticity. The effects of an initial imperfection on buckling deformation are studied in some detail. Postbuckling behavior is discussed in relation to undesirable effects on the fracture of cracked plates. The results of elastic analyses show that the magnitude of the stress-intensity factor increases after buckling. The results of elastic-plastic analyses and experiments show that the residual strength of cracked plates is reduced by the interaction between buckling deformation and plastic deformation at the ends of cracks.

A88-21216   A basic study of the accuracy estimation of structural analysis by the zooming method - Finite element analysis of the transverse bending of thin flat plates MASAAKI YOKOYAMA and SHIGERU SASAKI, *JSME International Journal* (ISSN 0913-185X), Vol. 30, Oct. 1987, pp. 1534-1542. 10 Refs.

A finite element analysis of problems related to the transverse bending of thin flat plates has been performed in order to derive an accuracy estimation method for structural analysis using the zooming method. The error characteristics of the bending moment are first obtained for the case of the uniform mesh division of a square plate and a circular plate. An accuracy estimation method is then proposed in which the existence range of the bending moment at a selected point is given as the sum of two errors: the accumulation of relative errors of the gradients on the zooming boundares, and the relative error of the bending moment at the selected point in the last zooming region. The method is demonstrated by application to 16 problems of various shapes.

A88-19820   Fatigue fracture toughness and crack propagation rate YOZO SAWAKI, SHUJI TADA, SHIGEHARU HASHIMOTO, and TADASHI KAWASAKI, *International Journal of Fracture* (ISSN 0376-9429), Vol. 35, Oct. 1987, pp. 125-137. 20 Refs.

The fatigue crack growth rates da/dN, of two high-strength steels were examined in air at different stress ratios, covering almost the entire range of stress intensity Delta(K) from nearly threshold value Delta(K)th to final fracture. The fatigue fracture toughness Delta(K)fc corresponding to the final fracture in fatigue was also determined. At lower Delta(K)fc, higher da/dN and reduced Delta(K)th are found. This correlation was analyzed quantitatively using the four-parameter Weibull function, and the stress-ratio dependency of the fatigue crack propagation curve was accounted for.

A88-23318   Report of the Institute of Industrial Science - The University of Tokyo YUTAKA TOI and TADAHIKO KAWAI, *Tokyo, University, Institute of Industrial Science, Report* (ISSN 0040-9006), Vol. 34, No. 1, Sept. 1987, pp. 1-58. 61 Refs.

The rigid bodies-spring models are extended to the discrete limit analysis of general thin-walled structures. The flat rigid plate element is formulated for arbitrarily shaped shell structures. This element consists of triangular rigid plates which are inclined to each other and connected with springs resisting relative displacements. Both geometrical and material nonlinearities are taken into account. The applications to the static and dynamic plastic collapse, the inelastic stability and the crushing problems are described with numerical examples.

A88-23317   Discrete limit analysis in structural mechanics YUTAKA TOI and TADAHIKO KAWAI, *Tokyo, University, Institute of Industrial Science, Report* (ISSN 0040-9006), Vol. 33, no. 6, Sept. 1987, pp. 213-274. 42 Refs.

New discrete models, called the rigid bodies-spring models, are described along with their applications to the plastic collapse analysis of solids and structures. For beams, plates, and framed structures, emphasis is placed on the dynamic collapse problems centering around the impulsive collapse, while static as well as dynamic collapse problems are discussed for some of standard shells, such as circular cylindrical and spherical shells. Plastic analysis of two-dimensional solid is also given.

A88-19199   Probabilistic approach to the certification of fatigue strength of composite structures TOSHIYUKI SHIMOKAWA, *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 36, Sept. 1987, pp. 947-953. 11 Refs.

The objective of this study was to investigate the probabilistic certification method for the fatigue strength of composite structures systematically and then to propose the use of the combination of the scatter factor of life and the scatter factor of fatigue strength. The equations

to express the mutual relationship between these two scatter factors and the combination of both factors were derived. Moreover, some calculation examples of the scatter factors were given by using the typical scatter parameters of fatigue life and fatigue strength obtained from the test results of carbon/epoxy laminate specimens. The assumptions made in this study were that: (1) fatigue tests of the composite structures provide an appropriate estimate of the central tendency of fatigue life; (2) the distribution form of fatigue life is the log-normal or two-parameter Weibull distribution; (3) the scatter parameters of fatigue life are known and independent of stress; (4) the shape of the S-N curve is linear on semilogarithmic or double-logarithmic graph paper; and (5) the slope of the S-N curve is known.

A88-13945   An alternating method for analysis of a group of interacting multiple elliptical cracks in an infinite solid TOSHIHISA NISHIOKA and YASUFUMI FURUTANI, *JSME International Journal* (ISSN 0913-185X), Vol. 30, Aug. 1987, pp. 1221-1228. 11 Refs.

An efficient alternating method is developed for the analysis of a group of interacting multiple elliptical cracks in an infinite solid. In this alternating method, an analytical solution for an elliptical crack in an infinite solid is used. To save computational time, geometrical symmetries of crack shapes and locations are effectively utilized in conjunction with the symmetry of the analytical solution with respect to the Cartesian coordinate system. Parametric studies on the interaction behavior of multiple coplanar elliptical cracks are made for several examples of problems. The stress intensity factors for those problems are determine efficiently and accurately by the present alternating method.

A88-13943   Two elastic half-planes bonded through an elastic layer weakened by two identical interface cracks SHOUETSU ITOU, *JSME International Journal* (ISSN 0913-185X), Vol. 30, Aug. 1987, pp. 1207-1211. 7 Refs.

Stresses around two symmetrically located interface cracks which lie in the composite materials constructed of two elastic half-planes bonded through an elastic layer are examined. To avoid the oscillatory stress singularities near the crack tips, the crack surface displacements are expanded in trigonometrical functions accompanied with the unknown coefficients. A modified version of the Schmidt method is used to determine these coefficients. Numerical calculations are carried out for the stress intensity factors.

A88-13567   Experimental investigation on interference effect of notch on strength of notched bar with double U-notches of unequal depth and radius TAMOTSU MAJIMA, HAJIME NAKAZAWA, TAKURO TOBITA, and YOSHIYASU KIMIZUKA, *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 36, Aug. 1987, pp. 871-877. 6 Refs.

The interference effect of double symmetrical U-shaped notches of unequal notch depth and/or unequal notch radius on the strength was investigated experimentally. The notch pitch range in which the general yield strength is reduced could be predicted by using the upper and lower bound theorems. An X-shaped extension of plastic deformation occurred in the notch pitch range influenced by the interference effect. The notch tensile strength was also reduced by the interference effect, as was the nominal mean stress at the net section at fracture. The magnitude of the reduction of notch strength ratio and notch pitch range due to the interference effect almost equalled that due to the general yield stress ratio. The difference in notch depth has a much stronger influence on the interference effect than the difference in notch radius does.

A87-50032 Free vibrations of pre-twisted plates (Fundamental Theory) TSUNEO TSUIJI and TEIYU SUEOKA, *JSME International Journal* (ISSN 0913-185X), Vol. 30, June 1987, pp. 958-962. 7 Refs.

The derivation of fundamental equations needed to investigate the free vibrations of thin pre-twisted plates is presented in this paper. Firstly, the strain-displacement relationships are derived by employing assumptions of the thin shell theory, and their simplified forms are proposed for plates having relatively large length-to-width ratios. Next, the principle of virtual work for the free vibration of the thin pre-twisted plates is formulated. The equation derived will be used to analyze the free vibrations of the thin pre-twisted plates by the Rayleigh-Ritz procedure.

A87-48074   Dependence of crack acceleration on the dynamic stress-intensity factor in polymers K. TAKAHASHI and K. ARAKAWA, *Experimental Mechanics* (ISSN 0014-4851), Vol. 27, June 1987, pp. 195-200. MOESC-supported research. 18 Refs.

The caustics method in combination with high-speed photography was employed to study velocity effect on the dynamic-stress-intensity factor of fast cracks in polymethyl methacrylate and in Araldite D. The specimen geometry was so determined that both the accelerating and decelerating crack propagation occurred noticeably in one fracture event. Instantaneous

crack velocity as well as its acceleration were expressed as a function of the crack length by using polynomials of the ninth order which were given on the basis of the least-square method. The results show that the dynamic-stress-intensity factor depends not only on the crack velocity but also on crack acceleration, and that the accelerating crack has a smaller value stress-intensity factor than the decelerating crack at the same velocity.

A87-49409 Study on the buffer characteristics of the honeycomb sandwich construction under dynamic loading TAKASHI KUNIMOTO and HITOSHI YAMADA, *Japan Institute of Light Metals, Journal* (ISSN 0451-5994), Vol. 37, May 1987, pp. 327-331.

In the sandwich constructions about one element of the honeycomb core, the buffer characteristics were studied theoretically and experimentally and the following results were obtained: (1) the maximum compressive load converges on a constant value with an increase in the impact speed; (2) 1/WV with respect to the momentum, is proportional to the point of some impact speed, and further that speed is constant about any form of the honeycomb core; (3) the mean crushing load has no relation to the impact velocity and the mass weight, and becomes nearly constant; and (4) the dynamic maximum compressive load is about 1.7 times the static value.

A87-46749 Formulation of distortional behavior of thin-walled cross-section beam KATSUHIKO TAKAMI and HIROSHI HIKOSAKA, *Kyushu University, Technology Reports* (ISSN 0023-2718), Vol. 60, Jan. 1987, pp. 9-16.

A formulation of distortional behavior of thin-walled cross-section beam is presented, and in this procedure the governing equations are derived from the principle of virtual work by assuming the strain field based on the modification of conventional beam theory. This new theory raises the precision of beam theory and expands the application field. The distortional behavior of curved box girders with some diaphragms is analyzed as an example. This case can be treated as the problem of one degree of freedom. The effects of the loading conditions and the diaphragms on the distortion of cross-section are studied.

A87-46748 Second-order displacement theory of thin-walled members with open cross section considering cross-sectional distortion and its application to the problems of inelastic buckling HIROSHI HIKOSAKA and YOSHIKAZU MARUYAMA, *Kyushu University, Technology Reports* (ISSN 0023-2718), Vol. 60, Jan. 1987, pp. 1-8. 5 Refs.

A method is presented for analyzing the interaction between local and overall instability of thin-walled open section members. On the basis of the beam theory approximations, nonlinear expressions for displacements are first derived by taking the distortion of cross section into account, and then the governing equations for instability of the members are developed. Buckling loads for H-section column are analyzed as an example. The accuracy of the method is discussed by comparing some solutions with those obtained by use of the more complex method based on the plate theory. This method makes it possible to predict the local to lateral instability through distortional instability of the members by using a small number of degrees of freedom.

A88-17136 On fatigue behaviors of adhesive bonded joints of FRP SATOSHI OKUDA, SHUJI NISHINA, and TETSUO WATANABE, *Proceedings of the 30th Japan Congress on Materials Research,* Kyoto, Japan, Sept. 1986, (A88-17126 05-23). Kyoto, Japan, Society of Materials Science, Japan, 1987, pp. 253-256.

The fatigue behavior of several adhesive bonded joints of glass-fiber reinforced plastic (FRP) was investigated at various environmental conditions. The adhesive bonded joints, made of orthophthalic acid unsaturated polyester reinforced with chopped strand glass mat or glass mat combined with general-purpose roving cloth, were subjected to relatively low-cycle tensile fatigue and bending fatigue tests. Results indicate that the fatigue behavior of adhesive bonded joints varies with the construction of overlaid bonded reinforcements of the fatigue specimen. Exposure to water was found to significantly decrease the fatigue strength of all adhesive bonded joints. Finally, dynamic creep behavior was found to be influenced by temperature: the deflection amplitude increases with increasing temperature, and the value of the number of cycles to failure is shifted to a lower value. The formula for estimation of the fatigue failure life is proposed.

A88-17131 Stress analysis and evaluation of fatigue strength of adhesive-bonded butt joint MAKOTO IMANAKA, WAICHIRO KISHIMOTO, KOH-ZOH OKITA, HIDEAKI NAKAYAMA, and MONPEI SHIRATO, *Proceedings of the 30th Japan Congress on Materials Research,* Kyoto, Japan, Sept. 1986, (A88-17126 05-23). Kyoto, Japan, Society of Materials Science, Japan, 1987, pp. 93-98. 9 Refs.

The paper describes a method for fatigue life estimation of lap joints, which is based on the assumption that fatigue strength of this type of joint is dominated by the tensile stress at the lap end rather than by the average shear stress over the lap length. The parameters needed for the application of this method include the value of the tensile stress at the lap end (determined from numerical results by FEM) and the S-N curve of adhesive-bonded thin-wall tube butt joint in which only the tensile stress is predominant. The results on the stress distributions of the lap joint showed that both the tensile and the shear stress were concentrated at the lap end, and the value of the maximum tensile stress at the lap end was higher than that of the maximum shear stress at the same location. The results of estimations of the fatigue strength agreed well with the experimental results; furthermore, the estimated values were conservative.

A88-17127 Stress intensity factor of cracked plate under moving thermal load EIICHI MATSUMOTO and MASANOBU TAKI, *Proceedings of the 30th Japan Congress on Materials Research,* Kyoto, Japan, Sept. 1986, (A88-17126 05-23). Kyoto, Japan, Society of Materials Science, Japan, 1987, pp. 1-6. 7 Refs.

The temperature distribution and the dynamic stress intensity factor of an infinitely long plate with an edge crack, which is under a moving thermal load, are analyzed numerically by the finite element method, using a triangular quarter point isoparametric element described by Barsoum (1977). The plate is assumed to be made of a linear elastic material, with zero contact thermal resistance between the plate surface and thermal load. Temperature distribution profiles and stress intensity factor contours are presented for some configurations of crack.

A87-47276 Evaluation of J-integral estimation procedures KENJI HAYASHI, HIROMASA KAWAMURA, and KOHSUKE HORIKAWA, *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 36, April 1987, pp. 334-340. 16 Refs.

The validity of the J-integral for incremental elastoplastic materials is established. Factors governing the path independence of the J-integral are examined with emphasis placed on the loading condition of an element in the vicinity of the crack tip. The results of FEM analyses based on the incremental plasticity theory are investigated to verify the adequacy of analytical assumptions used to develop formulas for estimating the J-values from a single load-displacement curve.

A87-41480 Theory for the decay of the wet shear strength of adhesion and its application to metal/epoxy/metal joints K. NAKAMURA, T. MARUNO, and S. SASAKI, *International Journal of Adhesion and Adhesives* (ISSN 0143-7496), Vol. 7, April 1987, pp. 97-102. 12 Refs.

A theory for the decay of the wet shear strength of adhesion has been produced by formalizing the quantitative relationship between wet shear strength of adhesion and moisture content. Theoretical values for the retention of wet shear strength of adhesion with time coincided with experimental data. It has been clarified that the diffusion coefficient of water is larger at the interface than in the adhesives, and that moisture absorption is determined by the diffusion of water at the interface.

A87-43206 Optimum design of hybrid laminated plates subject to axial compression (In the case of aspect ratio being less than unity) MITSUNORI MIKI and KOUJI TONOMURA, *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 36, March 1987, pp. 209-215. 9 Refs.

An analytical method useful for designing optimum hybrid plates subject to a given compressive load is presented. The hybrid plate is assumed to be symmetric and to consist of two high-performance surface layers and a low-performance core. The method is based on the flexural lamination parameter diagram of hybrid composites. The feasible design region where the constraint on the buckling load is satisfied becomes smaller as the core thickness ratio increases, and the region finally reduces to a point. The optimum fiber orientation at the surface and in the core and the optimum core thickness ratio can be obtained easily using the proposed method. It is found that neither the optimum fiber orientation of the surface nor that of the core is affected by the elastic constants or the fiber orientation of the other material. Thus, hybrid composites can be optimized by independent optimizations of each component material.

A87-43205 An approximate solution of stress field in unidirectional composites under tensile and thermal loading YOSHIHIRO TAKAO, TOSHIRO SUHARA, and WEN-XUE WANG, *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 36, March 1987, pp. 202-208. 11 Refs.

An approximate solution of the stress field in unidirectional composites was obtained for tensile and thermal loading conditions based on the Airy stress function. The hexagonal packing of unidirectional fibers was assumed as an ideal arrangement. This solution is applicable to the transverse-isotropic fiber/isotropic matrix composite system. Explicit solutions for the local stress and average strain of composite were presented together with the instruction for the numerical process. The average strain became equal to the expansion coefficient of composites when no tensile load was applied. The present results were compared with the previous exact solution obtained for glass/polymer composites and were found to be satisfactorily accurate. Finally, the stress along the fiber-matrix interface and the average axial stress in both matrix and fiber were presented as a function of fiber volume fraction for glass/epoxy and carbon/epoxy composites.

A87-46750 Nonlinear constitutive equations for plane stress and their application to composite laminates HIROICHI OHIRA, KAZUO KUNOO, KOUSEI ONO, NOBUHIDE UDA, and MASAKATSU OMORI, *Kyushu University, Technology Reports* (ISSN 0023-2718), Vol. 60, Jan. 1987, pp. 95-101. 10 Refs.

This paper presents a numerical method for predicting the nonlinear stress-strain response to symmetric laminated composites, consisting of orthotropic laminae, under in-plane loading. The stress-strain relation of a lamina is linear in fiber direction under uniaxial loading, but nonlinear in transverse direction and in shear. Ramberg-Osgood equations are introduced to represent nonlinear transverse and shear behavior of a lamina with great accuracy. The nonlinear behavior of laminated composite

materials is predictable by use of the nonlinear simultaneous equations based on classical lamination theory. Comparisons are made between numerical predictions and experimental results for some angle-ply laminates under uniaxial loading.

A87-53786 **Reliability degradation of structural components in the process of fatigue crack propagation under stationary random loading** HIROAKI TANAKA and AKIRA TSURUI, *Engineering Fracture Mechanics* (ISSN 0013-7944), Vol. 27, No. 5, 1987, pp. 501-516. 15 Refs.

Stochastic crack growth processes under stationary random loading are investigated by the use of an extended Markov approximation method. In order to reflect engineering reality of material inhomogeneity, the propagation resistance is also assumed to be random. A crack length distribution function is first derived in a closed form under some assumptions. It is found that the so-called cross effect does appear between the effect of randomness due to loading and that due to propagation resistance. Then, with the aid of this result, the discussion is made on how the reliability of structural components degrades with time in consideration of uncertainties associated with initial flaws. It is clarified that in the region of high reliability the influence of random loading becomes significant as the correlation time of the loading process increases. As an example, the results are applied to a problem on the determination of the inspection period.

A87-51169 **A fiber-reinforced matrix containing a penny-shaped crack under mode III loading condition** WEN-XUE WANG, YOSHIHIRO TAKAO, and TOSHIRO SUHARA, *International Journal of Engineering Science* (ISSN 0020-7225), Vol. 25, No. 7, 1987, pp. 855-869. MOESC-supported research. 15 Refs.

One of the fundamental problems related to the fracture of composite materials, that is, a penny-shaped crack in a fiber-reinforced matrix is solved under the Mode III loading condition, where the fibers are perpendicular to the crack plane and located along the crack border. An elastic fiber model is developed to the above torsional problem, yielding a Fredholm-type integral equation of the second kind for a set of fibers distributed symmetrically on a circle concentric with the crack. The integral equation is numerically evaluated, and the stress intensity factors are presented with the parameter of the fiber to matrix Young's modulus ratio for various geometries.

A87-47197 **Transient thermal stress problem in an orthotropic, thin plate with a Griffith crack** N. NODA, *Ingenieur-Archiv* (ISSN 0020-1154), Vol. 57, No. 3, 1987, pp. 175-181. 8 Refs.

In this paper, the transient thermal stress problem for an orthotropic thin plate with a Griffith crack perpendicular to the surfaces of the plate is considered. It is assumed that the transient thermal stress is set up by the application of heat flux to the surfaces of the crack and the heat exchange by convection on the surfaces of the plate. The analytical solution is found by Airy stress function. Numerical results indicate a dependence of the orthotropic stress intensity factors on the thermal and elastic constants over a certain parameter range.

A87-41567 **An expression for transient thermal stress in a nonhomogeneous plate with temperature variation through thickness** Y. SUGANO, *Ingenieur-Archiv* (ISSN 0020-1154), Vol. 57, No. 2, 1987, pp. 147-156. 5 Refs.

The transient-heat-conduction/thermal-stress problem is investigated analytically, extending the approach of Boley and Weiner (1960) to the case of an inhomogeneous flat plate with exponentially varying Young's modulus and thermal conductivity and arbitrarily varying (through the plate thickness only) thermal-expansion coefficient and Poisson's ratio. The derivation of the expressions and the solution technique are given in detail, and numerical results for several sample problems are presented graphically. Applications to the analysis of fiber-reinforced composites subjected to high temperatures (as in nuclear reactors, supersonic aircraft, or turbine engines) are indicated.

A87-40157 **Crack problem in a transversely isotropic medium with a penny-shaped crack under transient thermal loading** R. ISHIDA, *Zeitschrift fuer angewandte Mathematik und Mechanik* (ISSN 0044-2267), Vol. 67, No. 2, 1987, pp. 93-99. 7 Refs.

A theoretical approach is presented to find stress-intensity factors for transient thermal loading in an infinite transversely isotropic elastic medium with a penny-shaped crack, the surfaces of which are subjected to a sudden change of temperature. Variations of the stress-intensity factors with time are calculated and illustrated in figures.

A87-36931 **Impact response of a transversely isotropic cylinder with a penny-shaped crack** YASUHIDE SHINDO and HIDEAKI NOZAKI, *International Journal of Solids and Structures* (ISSN 0020-7683), Vol. 23, No. 1, 1987, pp. 187-199. MOESC-supported research. 7 Refs.

The axisymmetric dynamic response of a penny-shaped crack in a transversely isotropic infinite cylinder under normal impact is analyzed. Laplace and Hankel transforms are used to reduce the transient problem to a pair of dual integral equations in the Laplace transform plane. The solution is given in terms of a Fredholm integral equation of the second kind. A numerical Laplace inversion routine is used to recover the time dependence of the solution. The dynamic stress intensity factor is determined and numerical results for some practical materials are shown graphically to demonstrate the influence of transverse isotropy.

A87-36928 **Vibration and buckling of rectangular plates with nonuniform elastic constraints in rotation** T. MIZUSAWA and T. KAJITA, *International Journal of Solids and Structures* (ISSN 0020-7683), Vol. 23, No. 1, 1987, pp. 45-55. 28 Refs.

The spline strip method (Mizusawa and Kajita, 1984) is used to analyze the vibration and buckling of isotropic thin rectangular plates with nonuniform and continuous constraints against rotation. The values of rectangular plates determined for the case of a half-sine distribution of elastic constraints in rotation are found to be less than those of uniform constraints. The effect of nonuniform elastic constraints on the results is shown to be related to the aspect ratios and the rotational stiffness parameters of constraints.