

Japanese Aerospace Literature This month: *Advanced Materials*

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, 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)

A95-45285 Enhancement of tensile modulus and strength of braided composite. H. HAMADA, A. FUJITA, Z. MAEKAWA, and M. NAKAO (Kyoto Inst. of Technology, Japan), *Materials challenge diversification and the future; Proceedings of the 40th International SAMPE Symposium and Exhibition*, Anaheim, CA, 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. 654-664. 16 Refs. Documents available from Aeroplus Dispatch.

The braiding is one of the textile technologies which promises to improve the properties of the composites and to meet the requirements of automated fabrication. Moreover, preform of near-net shape of the component can be easily obtained by using the braiding technique. However, the braided composites possess the weaving structure with a braiding angle, so that modulus and/or strength of the braided composite become lower than those of unidirectional fiber composite. The purpose of this study is to fabricate new braided fabrics which can enhance the modulus and strength of the braided composites. The new fabric contains both braided and unidirectional parts and can be fabricated by using ordinary braiding machine. The tensile properties and notched strength were evaluated by varying the ratio of the braided part to the whole of specimen. The tensile properties and notched strength of the new braided composites increased up to 60%. (Author)

A95-45283 Properties of carbon fiber/bismaleimide prepreg system toughened with thermoplastic polyimide fibers. S. HAYASHI and M. SUGIMORI (Mitsubishi Rayon Co., Ltd., Nagoya, Japan), *Materials challenge diversification and the future; Proceedings of the 40th International SAMPE Symposium and Exhibition*, Anaheim, CA, 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. 621-631. 5 Refs. Documents available from Aeroplus Dispatch.

The current carbon fiber reinforced bismaleimide composites provide fairly good thermal and mechanical properties and superior processabilities compared with thermoplastic polyimide composites. However, they reveal poor damage tolerance, which has restricted their usage in structural application under high temperature service condition. By applying a new inter-layer toughening technique, we have developed a toughened BMI prepreg system. In this prepreg system, thermoplastic polyimide fibers are used as toughening materials. The prepreg has good handling characteristics. In addition, the cured laminates show significantly improved damage tolerance and good hot/wet mechanical properties. High temperature structural materials should have good aging properties as well. We also have evaluated the isothermal aging properties of this toughened BMI Composite. The results obtained are presented, and the toughening mechanism is also 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, 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)

A95-43948 Effects of additives on sintering and mechanical properties of alumina. T. NAGAOKA, M. YASUOKA, K. HIRAO, and S. KANZAKI (Nagoya, National Industrial Research Inst., Japan), *5th International Symposium on Ceramic Materials and Components for Engines*, Shanghai, China, 1994, Proceedings (A95-43894 12-27), Singapore, World Scientific, 1995, pp. 469-472. 8 Refs. Documents available from Aeroplus Dispatch.

The effect of small amounts (0-3 wt%) of CaO additives on sintering, microstructure and mechanical properties of Al_2O_3 doped with 0.5 wt% MgO was investigated. During sintering, small amounts (0-3 wt%) of CaO reacted with Al_2O_3 to form, in situ, a large volume (0-38 vol%) of platelike grains of calcium-hexaaluminate in an Al_2O_3 matrix. It was found that the addition of more than 1 wt percent CaO suppressed the sinterability of Al_2O_3 . However, dense Al_2O_3 with over 97% of theoretical density was obtained by addition of up to 2 wt% CaO at 1650 C for 4 h in air. This inhibited the abnormal grain growth of Al_2O_3 and improved its flexural strength, suggesting that the thermal shock fracture resistance of the CaO-doped material should be higher than that of pure Al_2O_3 . (Author)

A95-43900 Silicon nitride materials for heat engine applications. K. KOGA (Kyocera Corp., Kokubu, Japan), *5th International Symposium on Ceramic Materials and Components for Engines*, Shanghai, China, 1994, Proceedings (A95-43894 12-27), Singapore, World Scientific, 1995, pp. 70-75. 6 Refs. Documents available from Aeroplus Dispatch.

Compositions in the silicon nitride rare-Earth oxide-silica ternary system were selected for heat engine applications. Effects of the microstructure and the grain boundary composition on mechanical and chemical properties of the silicon nitride material were studied, focusing on the molar ratio of silica and rare-earth oxide and the relation between the fracture toughness and the residual stress on silicon nitride crystal. The performance of the silicon nitride turbine rotor was estimated by CARES program with using a multiaxial fracture criterion. The results of the calculation showed good agreement with the experimental results of the turbine rotor burst test. (Author)

A95-42718 VAMAS round robin on fracture toughness of silicon nitride. M. MIZUNO and H. OKUDA (Japan Fine Ceramics Center, Nagoya) *American Ceramic Society, Journal* (ISSN 0002-7820), Vol. 78, No. 7, 1995, pp. 1793-1801. 21 Refs. Documents available from Aeroplus Dispatch.

Eight laboratories in Germany, Japan, U.K., and U.S. participated in the VAMAS round robin. The fracture toughness of silicon nitride at room temperature and at 1200 C was measured by three methods: the single-edge V-notched beam (SEVNB), single-edge precracked beam (SEPB), and chevron notched beam (CNB). The obtained values show hardly any crosshead speed dependence, irrespective of test temperature and atmosphere. Results may have been influenced by a small amount of slow crack growth, but distinct R-curve behavior could not be detected within the scope of the tests. The values at 1200 C in N_2 can be measured by the SEVNB and SEPB methods with small scatters. The oxidation of silicon nitride, caused by heating in air, increases the SEVNB and SEPB values. The CNB values are free from the effects of test temperature and atmosphere, but they show a large scatter between laboratories. However, the chevron V-notched beam (CVNB) method, which is an improved CNB method, shows values with a small scatter, irrespective of the measurement conditions. (Author)

A95-42223 Dependence of strength on size of flaw dominating fracture in ceramics. T. HOSHIDE and M. MASUDA (Kyoto Univ., Japan), *Materials Science Research International* (ISSN 1341-1683), Vol. 1, No. 2, 1995, pp. 108-113. 19 Refs. Documents available from Aeroplus Dispatch.

Four-point bending tests using silicon nitride and alumina were carried out to clarify the relation between the strength and the size of flaw observed at a fracture origin. When the fracture originated from a smaller flaw, the strength was confirmed to be lower than that expected from the fracture toughness criterion. A convenient procedure using the mean strength and the fracture toughness is proposed to estimate the strength degradation dependence on flaw size. A new model was also developed assuming the stable cracking caused by the separation per one grain ahead of a flaw prior to the final unstable fracture. A Monte Carlo simulation based on the proposed model was done to explain the anomalous behavior of a small flaw. The relation of strength vs. crack length simulated by taking account of grain-size distribution showed good agreement with the experimental result. A suggestion is made for estimating the lower bound in the scatter of strength dependence on flaw size by using the size of the largest grain expected in the material. (Author)

A95-42188 Crack growth resistance due to shot peening in carburized gears. K. INOUE and M. KATO (Tohoku Univ., Sendai, Japan), *Journal of Propulsion and Power* (ISSN 0748-4658), Vol. 11, No. 5, 1995, pp. 973-979. 19 Refs. Documents available from Aeroplus Dispatch.

This article deals with the effect of shot peening on crack growth in carburized gears. Since residual stress plays an important role in this analysis, an evaluation of the residual stress induced in a carburized gear tooth due to shot peening is presented first. It has been proposed on the basis of the assumption that the residual stress is caused by the difference of volume expansion between the case and the core, and the influence of both the reduction of retained austenite and the strain caused by shot peening are considered. The shot peening is fairly effective for the reduction of fatigue crack growth rate. The resistance to crack growth is demonstrated by the simulation of crack propagation in both the carburized gear and the shot-peened gear. (Author)

A95-40502 In-situ measurement of bending strength of TiC whiskers in the scanning electron microscope. Y. SEINO, S. SHIN, and S. NAGAI, (National Research Lab. of Metrology, Tsukuba, Japan), *Ceramic matrix composites—Advanced high-temperature structural materials; Proceedings of the MRS Symposium*, Boston, MA, 1994 (A95-40497 11-24), Pittsburgh, PA, Materials Research Society (MRS Proceedings, Vol. 365), 1995, pp. 35–40. 11 Refs. Documents available from Aeroplus Dispatch.

The three-point bending strength of TiC whiskers was measured in a scanning electron microscope. The whisker samples have 50- μ length and 2–4- μ diam and are commercially available as reinforcements for composite materials. The distribution of the bending strengths of the whiskers showed a double peak around 5.2 and 30.4 GPa, respectively. The difference in these values is attributed to differences in the cleavage strength of two crystal planes depending on whisker growth direction. (Author)

A95-39364 Effects of attacking sequences on mechanically fastened joint strength in quasi-isotropic carbon-epoxy laminates. H. HAMADA, K. HARUNA, and Z. I. MAEKAWA (Kyoto Inst. of Technology, Japan), *Journal of Composites Technology and Research* (ISSN 0885-6804), Vol. 17, No. 3, 1995, pp. 249–259. 13 Refs. Documents available from Aeroplus Dispatch.

The desire to develop adequate strength, particularly at bolt hole, tends to restrict the choice of fiber patterns to those that do not deviate very far from a quasi-isotropic pattern. The weakest parts of a composite structure are the joint parts; therefore, the effective stacking sequences on joint strength while maintaining the isotropic nature have to be cleared. In this study, the effect of stacking sequences on quasi-isotropic T300/2500 joint strength was examined. Two joint geometries that exhibited bearing failure and net-tension failure under pin-bearing loads were chosen. Six types of laminate configurations were examined in quasi-isotropic patterns. According to observation failure mode and acoustic emission (AE) measurement, the evidence of the effect of stacking sequences was made clear. The highest bearing and net-tension strength obtained from the quasi-isotropic laminates tested all had 0 deg plies on the outer surfaces, 90 deg plies next to the 0 deg plies, and +/–45 deg plies interspersed in the middle of the laminate. (Author)

A95-38089 Extremely sensitive dependence of strength after proof testing of ceramics on initial strength. M. ICHIKAWA (Univ. of Electro-Communications, Chofu, Japan), *Materials Science Research International* (ISSN 1341-1683), Vol. 1, No. 1, 1995, pp. 59–64. 15 Refs. Documents available from Aeroplus Dispatch.

It is shown in proof testing of ceramic components that the phenomenon that strength after proof testing, $S(f)$, depends quite sensitively on initial strength, $S(i)$, appears under certain conditions. For example, a slight difference of $S(i)$ of only 0.005 MPa results in a large difference of $S(f)$ of some 400 MPa. The reason and conditions for this phenomenon are investigated theoretically. It is shown that this phenomenon appears when the unloading stress rate is considerably low and the crack growth exponent n is large as in ceramics. Practical aspects of the phenomenon are also discussed. (Author)

A95-38088 Evaluation of Weibull parameters for static strengths of ceramics by Monte Carlo simulation. T. TANAKA (Ritsumeikan Univ., Kusatsu, Japan), H. NAKAYAMA (Osaka Sangyo Univ., Daito, Japan), A. SAKAIDA (Akashi College of Technology, Japan), and T. IMAMICHI (Shiga Prefecture, Industrial Research Center, Japan) *Materials Science Research International* (ISSN 1341-1683), Vol. 1, No. 1, 1995, pp. 51–58. 18 Refs. Documents available from Aeroplus Dispatch.

The Monte Carlo simulation method was used to evaluate the theoretical distributions of the estimates of Weibull modulus and scale parameter for various sample sizes. It was found that the theoretical distributions of the estimates of Weibull modulus and scale parameter are well approximated by log-normal distributions, and the scatter and bias of each distribution decrease with increase of sample size. Comparison of the distribution of Weibull modulus estimated by experiments with the theoretical distribution indicates that the scatter of the experimentally obtained Weibull modulus results from the statistical nature of the estimates depending on the sample size and that the difference of test conditions is not a major factor for the scatter. It was also revealed that the distribution of scale parameter obtained by experiments does not agree with the theoretical one obtained by Monte Carlo simulation. This means that the scale parameter or the intrinsic strength of sintered silicon nitride and sintered silicon carbide depends on the fabrication and testing techniques. (Author)

A95-37145 Conductivity and strength behaviour of alumina (whisker)—zirconia composites C. S. MONTROSS, B. A. VAN HASSEL, T. KAWADA, H. YOKOKAWA, and M. DOKIYA (National Inst. for Materials and Chemical Research, Tsukuba, Japan), *Journal of Materials Science* (ISSN 0022-2461), Vol. 30, No. 12, 1995, pp. 3285–3290. 18 Refs. Documents available from Aeroplus Dispatch.

Yttria stabilized zirconia (8 mol pct) composites were fabricated by tape casting with either alumina powder or alumina whiskers, and pressureless sintered. Sintering behavior, ionic conductivity, and mechanical strength were analyzed. For all compositions analyzed, increasing alumina content reduced the sintered density. For whisker-reinforced zirconia, the rigid whiskers prevented matrix densification along their axis. The ionic conductivity was measured by the complex impedance method from 500–1000 C, and the

activation energy for ionic conduction calculated over that range. The ionic conductivity of the alumina-zirconia composites decreased with increasing alumina content as expected by the rule of mixtures. However, the ionic conductivity of the whisker zirconia composites decreased more than expected possibly due to contamination from the whiskers. The strength of the whisker zirconia composites was also found to be affected by the porosity. At 5 vol%, the average strength was measured at 39.9 kgf/sq mm, which decreased to 24 kgf/sq mm at 20 vol%. (Author)

A95-35437 Influence of coating configuration on cyclic thermal shock fracture behavior of plasma sprayed coatings. M. FUKUMOTO, (Toyoashi Univ. of Technology, Japan), T. YAMASAKI (Nippon Sharoy Seizo Co., Ltd., Japan), and I. Okane, (Toyoashi 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, 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)

A95-35427 Application of a ductile metallic phase toughening mechanism to ceramic/metals functionally graded materials. K. HIRANO (Agency of Industrial Science and Technology, Tokyo, 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. 301–306. 10 Refs. Documents available from Aeroplus Dispatch.

It is still essential to improve the fracture toughness of high-strength engineering ceramics for wide use in primary structural applications. The purpose of this study is to establish toughening design concepts for ceramics. First, the ductile metallic phase toughening mechanism for ceramics, proposed previously, is introduced. Then, it is shown that the fracture toughness for ceramics is successfully improved as theoretically estimated from this concept. Finally, the mechanism is also applied to ceramic/metal functionally graded materials, and the possibility of improvement of fracture toughness without the reduction of strength is confirmed. (Author)

A95-35413 Prestressed toughened $Al_2O_3/Cr_3C_2/Ni/Al_2O_3/Cr_3C_2$ with symmetric gradient structure. Y.-S. KANG and Y. MIYAMOTO (Osaka Univ., Ibaraki, 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. 115–120. 9 Refs. Documents available from Aeroplus Dispatch.

Symmetrically arranged functionally gradient materials in the system $Al_2O_3/Cr_3C_2/Ni/Cr_3C_2/Al_2O_3$ were fabricated by SHS/HIP. Owing to the symmetric structure with different thermal expansion rates of the outer Al_2O_3 ceramic and inner Cr_3C_2-Ni tough layers, a strong compressive residual stress up to 845 MPa was induced in the outer Al_2O_3 layer, which remarkably reinforced the mechanical properties of the Al_2O_3 ceramics. The hardness and indentation fracture toughness of the Al_2O_3 was as high as 22 GPa and 11 MPa \times sq rt m, respectively. The flexural strength of the symmetric FGMS was 900 MPa. (Author)

A95-35412 Elaboration of symmetric functionally gradient materials of the $Al_2O_3/TiC/Ni/TiC/Al_2O_3$ system. Z. LI, K. TANIHATA, and Y. MIYAMOTO (Osaka Univ., Ibaraki, 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. 109–114. 8 Refs. Documents available from Aeroplus Dispatch.

Symmetric functionally gradient materials of the $Al_2O_3/TiC/Ni/TiC/Al_2O_3$ and Al_2O_3-30 wt.% $TiC/TiC/Ni/TiC/30$ wt.% $TiC-Al_2O_3$ were fabricated by SHS/HIP. Use of conventional additives such as MgO and Mo₂C were useful to control the gradual change of microstructures. Strong compressive residual stress as high as 200–300 MPa was induced in the outer layers due to the compositionally symmetric structures, resulting in remarkable reinforcement of mechanical properties of the outer ceramics. Moreover, new intelligent functions such as flaw tolerance and preferential crack propagation in a safe direction appeared. The symmetric gradient structure can create higher order functions than inherent material properties. (Author)