Summary

The 44 papers included in this publication cover various aspects of thermomechanical and physical behavior of composites which have been studied over the past two years both in the United States and Japan. For convenience, the aspects covered are grouped into nine subject areas: Fracture, Fatigue, Stress Analysis, Dynamic Behavior, Design, Fabrication Methods, Testing Methods, Elevated Temperature and Environmental Effects, and Thermomechanical Properties. Brief summaries of the nine subject areas will be given.

Fracture

The fracture process of various composite systems is investigated. Although laminated composites were focused on in most papers, new types of composites were also examined; for example, helical fiber reinforced ceramics, and steel fiber reinforced polymer cement composites. Fukuda discussed a model to calculate the stress concentration factor of the nearest fibers adjacent to a broken fiber in an unidirectional hybrid composite. Drzal and Rich studied the effect of various surface treatments of fiber on the interfacial shear strength and found that some surface finishes resulted in a brittle zone between fiber and matrix, thus increasing the interfacial shear strength. Fracture toughness by three-point bending test was measured on a helical tantalum fiber/silicon carbide composite by Kagawa et al and on steel fiber/polymer cement composite by Horiguchi. Failure mechanism in laminated composites were studied by focusing on transverse ply failure by Kister et al, on a curved free-edge by Klang and Heyer, while the initial and post failure in the stress-strain curve of the composite was studied by Ohira and Uda.

Fatigue

Fatigue damage was focused on from various viewpoints, causes of damage, and measurement methods. Tsangarakis et al investigated the tension-tension fatigue damage of a fiber-reinforced fiber/aluminum composite and found that fabrication defects reduced the fatigue limit, but the fiber imperfection and cyclic frequence did not. Techniques measuring fatigue damage were discussed on a notched laminated composite by Kress and Stinchcomb and also by Cantrell et al. Kress and Stinchcomb attempted to correlate "damage states" to the other mechanical properties and Cantrell et al proposed a new ultrasonic measurement technique which picks up only "real damage" in composites but not pseudo-damage such as surface irregularity. Harris and Morris reported on the experimental results on the compression-compression fatigue of a notched laminated composite and found that its fatigue life is a strong function of stacking sequence or specimen thickness.

Stress Analysis

Stress analysis is grouped into two areas: analytical and numerical techniques. Mura and Taya solved the thermal residual problem in a short fiber metal matrix composite by using the concept of Somigliana dislocations and Eshelby's equivalent inclusion. Rehfield et al calculated analytically the stress field in a tabbed compression specimen to identify the possible failure point in the specimen. A similar attempt was made by Cunningham et al on the stress field in and around the end tabs of a composite specimen, and they found that the best tab design to reduce the stress concentration and to yield consistent experimental results has a 10-deg tab angle and no cutoff thickness. The Saint-Venant effect in composite plate was studied numerically by Okumura et al, who found that the rate of attenuation of nonuniform local stress distribution is smaller in composite than in isotropic plate. Akasaka and Asano developed a numerical method based on an extremum principle of total potential energy and computed the stress and deformation of a sandwich panel having curved faceplates under pressure loading. The numerical results on the strains and deformations were compared with the experiment, resulting in good agreement between them.

Dynamic Behavior

Various aspects of dynamic behavior of composite were focused on: acoustic damping, wave propagation, impact, and buckling. Acoustic damping in composite was studied on stiffened graphite/epoxy panel subjected to also static shear load by Soovere and on ferrite-resin composites by Yamauchi and Emoto. Soovere studied the effect of a high random acoustic load together with static shear load near initial buckling on the dynamic response of integrated stiffened graphite/epoxy panels both experimentally and analytically and found that the damping in noncritical modes can increase by as much as a factor of four at initial buckling. Yamauchi and Emoto found in their experiment on ferrite-resin composite that the factor affecting the damping coefficient (DC) most is the thickness of metal coating on the composite plate, and the value of DC was not influenced much by the frequency. The mechanism and behavior of low-velocity impact on composites were studied by Chamis and Sinclair and also by Ross et al. Chamis and Sinclair studied impact resistance of unidirectional composite by use of a Charpy tester with the aim of studying the energy-absorbing mechanisms. They also examined several analytical models, that is, mechanistic, statistical, and transient finite-element-method models. The last model was attempted on a laminated composite in detail by Ross et al, who compared the numerical results by the 3-D finite element method with the experiments and obtained good agreement between them. The buckling behavior of viscoelastic composite columns was studied analytically by Wilson and Vinson, who used a quasi-static approach and found that the viscoelastic effects are significant in reducing the critical buckling load by 10 to 20%.

Design

Design was discussed in two aspects: optimum design of the composite itself in selecting the best combination of fiber type with its alignment and matrix material, and the design of composite structures made of various composite materials, most often laminated composites. Miki reported a design method for a laminated composite with required flexural stiffness. In Miki's method, three parameters—fiber type, matrix type, and ply angle—are determined at the end of optimization process. Morita et al obtained two optimum compositions of fibers in hybrid composites used for the magnetic powder core of the magnetic wedges in an induction motor. The main objective in their work was to enhance the flexural strength by keeping a certain level of permeability. Ko and Pastore studied the design of a 3-D fabric composite in order to obtain the accurate prediction of its strength. The analytical model is based on a maximum failure criterion and the predicted value agreed well with the experiment. Kawashima et al investigated experimentally the optimum design of three composite structures that are to be used for space structural components. The evaluation of these composite structures was made by subjecting them to acoustic noise environment, thermal cycling, and sinusoidal vibration.

Fabrication Methods

Fabrication conditions on various composites were reported, aiming at improving the mechanical properties of a composite. Cho and Okura studied processing conditions on a carbon-carbon composite where the matrix is pulverized coke, and three types of fiber were examined, that is, short, long fibers, and cloth. The evaluation of the c/c composite fabricated was made by measuring the bending strength. They found that the composite with long fibers has the best bending strength. The method fabricating silicon carbide fiber/aluminum composite by slurry impregnation and liquid phase hot pressing was discussed by Kohara and Muto, who found that as the volume fraction of fibers increases, a departure of the strength from the value of a rule of mixture is enhanced and addition of silicon to the aluminum matrix is effective in reducing the degradation of silicon carbide fibers. Nimmer et al examined the fabrication and design criteria for two types of composite flywheels and also reported some fabrication methods for thicker flywheels by hydroclaving process. Minoda et al discussed the curing condition of an integrated graphite/epoxy laminated composite and proposed a new testing method, in-process direct measurement of electrical properties of articles in an autoclave in order to better monitor the cure cycles of the composite.

Testing Methods

Further efforts in improving testing methods were made by several researchers. Daimaru et al measured the work of fracture (γ_F) of continuous and short fiber metal matrix composites by a three-point bending test. The specimen has a center notch with a triangle ligament. The analytical model proposed by Daimaru et al predicted the experimental values of γ_F very well. Oplinger et al examined various types of tension specimens both experimentally and numerically. They concluded that the tension specimen with a streamline shape is quite promising for laminated composites and ceramics, and it is a good alternative one to tabbed specimens when the tabbed specimens cannot be used under a more stringent environment. Nimmer and Trantina discussed two testing methods to measure the strength of composites, the ASTM three-point flexural test and ordinary tension test, and concluded that the strength measured by the ASTM flexural test overestimates the true strength. Kobayashi and Suemasu studied the dynamic crack propagation in a glass fiber composite by measuring the crack velocity and the temperature increase due to the energy dissipation at a crack tip. They reported an improved dual-layer liquid crystal film method to record the temperature distribution.

Elevated Temperature and Environmental Effects

Metal matrix composites are often used at high temperatures. Thus, three papers studied the microscopic behavior of metal matrix composites at high temperatures, and the other two papers discussed the environmental effects on composites. Rhodes and Spurling studied the growth kinetics of the reaction zone products in SiC/Ti-6Al-4V composites and found that the major product is titanium carbide, among others, and its growth obeys a diffusion type law, that is, the thickness is proportional to $(\text{time})^{1/2}$. In order to avoid reaction products, Umekawa et al used coated fibers for two types of metal matrix composites, tungsten/nickel and tungsten/SUS316, and concluded that zirconium compounds were effective as a coating material for these composites. Internal friction measurements were made on oxide dispersion-strengthened nickel-chromium (Ni-Cr) alloys at various temperatures and frequencies by Shioiri and Satoh, and the activation energy of the grain boundary viscosity was obtained from the peak component and will provide useful data for the analysis of the creep behavior of Ni-Cr alloys. Aylor and Kain investigated the corrosion resistance of several aluminum-based metal matrix composites in a marine environment. The metal matrix composites investigated are continuous and short silicon carbide fiber/aluminum and continuous graphite/aluminum composites. Since all the composites used were found to show excessive corrosion, some suitable coatings were recommended. Hahn et al studied the behavior of a composite flywheel in vacuum and at 100°C and found that the static properties of the compósite were not degraded significantly and that the fatigue strength was not reduced at all after exposure to vacuum and 100°C.

Thermomechanical Properties

In order to use composite as a structural component, the thermomechanical properties of the composite must be found either experimentally or analytically. One of the most accurate methods to determine the elastic constants is the wave propagation method. This was studied by Kritz and Ledbetter on unidirectional graphite fiber/epoxy composites. Additional findings in their work were that shear wave velocity exceeds longitudinal wave velocity in the plane transverse to the fiber axis. In the standard analysis of the mechanical properties of composites, the shear modulus (G) of the matrix has been always assumed to be constant. Hayashi challenged this assumption and showed experimentally in a combined shear and compression test that G becomes a function of the compressive stress.

Takao proposed a new model to predict the thermal expansion coefficients of a hybrid short fiber composite with fibers being misoriented two- or three-dimensionally. Unlike the conventional approach based on laminate theory, this model accounts directly for the interaction between misoriented short fibers by use of Eshelby's method. Although most of the studies on the mechanical properties of the composite are focused on the static properties, a knowledge of the mechanical properties at high strain-rate becomes equally important under some circumstances. Kawata et al obtained such data experimentally on dual-phase steel and graphite/glass/epoxy hybrid composites at high strain rates. They found that dual-phase steel showed considerable ductility at high-velocity impact compared with the matrix pure iron, and graphite/glass/epoxy composites also showed considerable ductility at high-velocity impact despite the fact that usually graphite/epoxy composites are brittle under high velocity impact.

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