

Literature Reviews

Failure Criteria for Composite Structures

Report reviewed by K. L. Reifsnider, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

REFERENCE: Mast, P. W., Beaubien, L. A., Mulville, D. R., Sutton, S. A., Thomas, R. W., Tirosh, J., and Wolock, I., "Failure Criteria for Composite Structures," Naval Research Laboratory Memorandum Report 5231, 1984.

This article is part of the final report of a multidisciplinary program initiated in July 1975 to provide information on graphite-fiber-reinforced composite materials and improved adhesives for potential use in Navy aircraft. It discusses the results of the application of the automated in-plane loader developed at the Naval Research Laboratory that uses three independent computer-controlled hydraulic actuators coupled to a movable head to apply combinations of horizontal displacements (in-plane shear), vertical displacements (tension or compression), and rotational displacements (in-plane bending). Single-edge-notch specimens, with dimensions of 25 by 30 by 2 mm having a 15-mm notch parallel to the 25-mm dimension, were tested. Load, displacement, and energy dissipation data were collected by the system, and specimens were mounted automatically from a magazine. The test arrangement and configuration enabled large data sets to be generated for a wide range of loading parameters. Reproducibility of the data was high.

Specimens were made from graphite fibers in three different resin systems (Narmco 5208 epoxy, Hexel F178 bismaleimide, and a phthalocyanine C-10 developed at the Naval Research Laboratory) and were fabricated with stacking sequences of $[\pm\alpha_n]_s$ and $[0, \pm 45, 90]_2$. Two temperature levels were used, room temperature and 232°C (450°F).

The loading details and method of presentation are shown in Fig. 1. Also shown are surface plots of failure data for several stacking angles as a function of the loading variable defined in the loading diagram. One can see an expected drop in strength for increasing Mode-1 loading and low values of (negative) in-plane bending.

Figure 2 shows a similar (but now a four-quadrant) plot for several different stacking angles. A number of crossovers and other peculiarities are seen, especially for the low-angle stacking cases.

Figure 3 shows a cut of the contours for $\theta_2 = 0$ from the quasi-isotropic data at 232°C. The differences in failure levels (maximum load levels in this case) at elevated temperature are smaller than for the room-temperature test data of the same laminate.

The conclusions drawn by the authors are quoted below.

1. Comprehensive data characterizing the failure behavior of fiber-reinforced composites is quite complex. It cannot be represented by the usual methods—a simple equation or simple graph. Automated techniques are needed to analyze and utilize the data properly. As was apparent in this report, it is necessary to simplify the data to discuss it or compare it using conventional methods.

2. For the range of resins studied in this investigation—a standard epoxy, a bismaleimide, and a phthalocyanine—there is little difference in the in-plane fracture toughness of composites made with these resins at room temperature and at elevated temperature. Composites exhibit significant in-plane fracture toughness at temperatures significantly higher than what is considered to be the maximum use temperature of the resin matrix. These observations indicate that the in-plane fracture

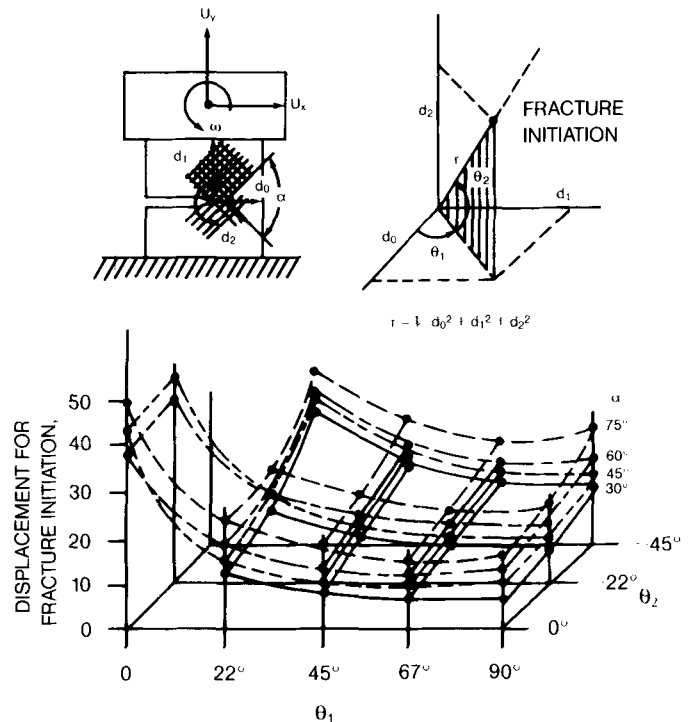


FIG. 1—Failure surfaces for Thornel 300/5208 composite for several angles of lay-up (α) in one octant of load space (Fig. 5 of Mast et al).

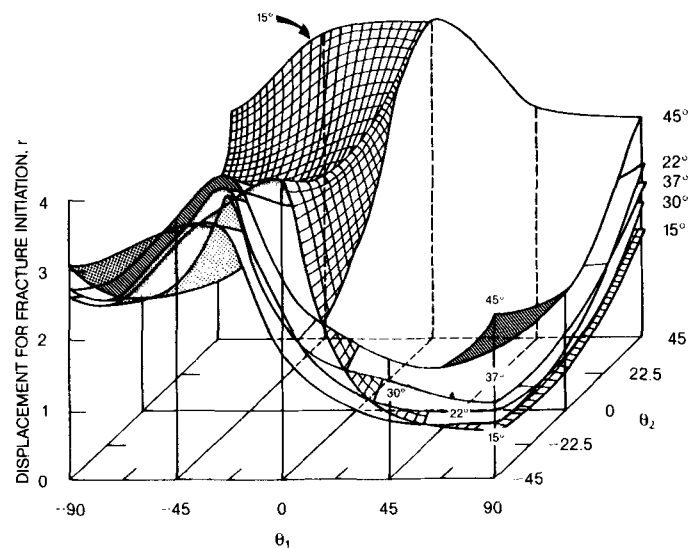


FIG. 2—Series of failure surface for different reinforcement included angles (Fig. 8 of Mast et al).

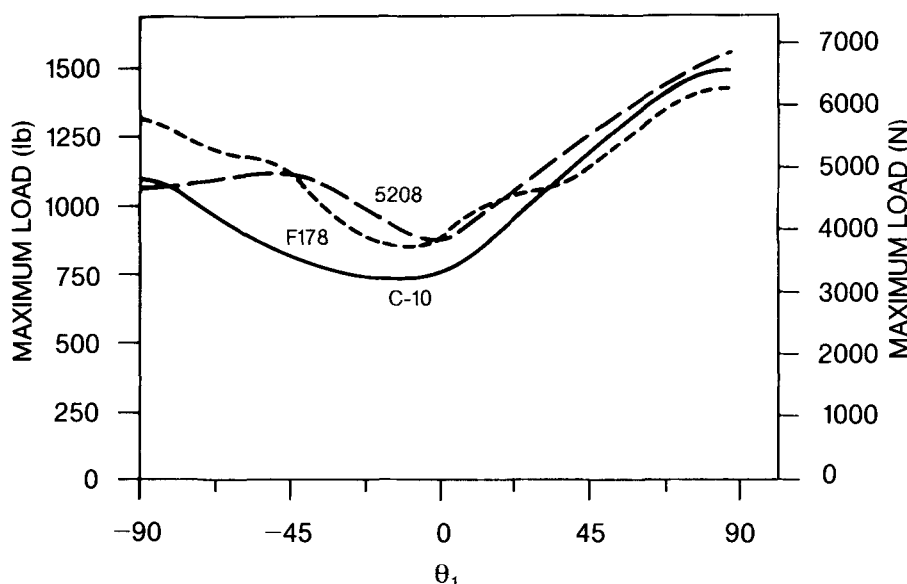


FIG. 3—Comparison of 232°C (450°F) failure curves for T300/5208, T300/F178, and T300/C10. $r_2 = 0$, reinforcement angles = (0°, +45, 90°) (Fig. 26 of Mast et al, SI units added).

toughness of fiber-reinforced composites is dominated by the fiber and that significant variations in matrix properties have little effect.

The results of the test series were used in a concept of "similar strain fields" to predict failure loads and location in the fracture test of a box beam with good correlation between predictions and observations.

This report is interesting and useful, especially in the context of producing large data bases for wide ranges of material, loading, and environmental test (or service) conditions. Although "toughness" of a composite is not a clear concept, the work by the authors indicates that the failure experience gained from small coupons can be used to predict failure of structures if the test experience is carefully matched to the component experience. Although this "brute force" approach has the disadvantage of requiring extensive testing to match data with all possible service eventualities, it has the advantages of being direct and reasonably convenient. Although there is no guarantee that the specimen configuration and interpretation schemes will always provide general agreement between test data and component experience, the results obtained by the authors suggest that one can expect the associations between coupon test data and structural behavior to be significant and reliable, and the discrepancies to be more specific than general. Such a test scheme can provide valuable material comparison data that are strongly associated with fracture strength.

Ceramic Coatings for Heat Engine Materials—Status and Future Needs

Report reviewed by K.L. Reifsnider, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

REFERENCE: Lackey, W. J., Stinton, D. P., Cerny, G. A., Fehrenbacher, L. L., and Schaffhauser, A. C., "Ceramic Coatings for Heat En-

gine Materials—Status and Future Needs," in *Proceedings of International Symposium on Ceramic Components for Heat Engines*, October 17-21, 1983, Hakone, Japan.

This paper is a summary of a later report by the same title that reviews the status and future potential for application of ceramic coatings in advanced diesel and turbine engines.¹ What makes the article of special interest is the role of composite materials in this important area of technology. The authors state the case for ceramics as follows:

Ceramics, in contrast to metals, generally exhibit better structural and thermal capabilities at high temperatures. In general, ceramics are more resistant to creep, oxidation, corrosion, and wear, as well as being better thermal insulators. The benefits of thermal barrier coatings on the hotter side of diesel or turbine engine components are well documented, and thermal barrier coatings are one among several applications of ceramics that are being actively pursued for heat engines. Ceramic coatings are being considered for diesel engine cylinder liners, piston caps, valve faces and seats, piston rings, and other parts and for turbine components such as combustors, blades, stators, seals, and bearings.

The authors present a sample of properties for about 25 ceramic materials (in high-density high-strength form) in a single table, with the caution that the properties of coatings of those materials may be different from those shown. They also discuss the relative merit of the thermal shock parameter quoted in the table. A review of coating technology (deposition methods, process diagnostics, and coating microstructures) is presented, as well as a discussion of various ZrO₂-based thermal coatings. Wear- and erosion-resistant and low-friction coatings also are reviewed.

Composites enter this technology in several ways:

The dispersoid-ceramic matrix composite is an example of novel microstructures that are possible with newly emerging coating technologies. Coating, particularly chemical vapor deposition, is an attractive method for preparation of ceramic matrix composites containing either

¹Oak Ridge National Laboratory, Report ONRL/TM-8959, 1984.

a dispersed ceramic or metallic particulate phase or ceramic fibers. Chemical vapor deposition can produce a material having high density, fine grain size, and superior properties compared with monolithic ceramics fabricated by powder techniques [1] or coatings prepared by other methods. Hirai and coworkers have chemically vapor deposited Si_3N_4 -matrix composites containing sufficient concentrations of very small dispersed particles of TiN, BN, C, and SiC to beneficially influence mechanical and physical properties [2].

Also, reinforced-composite lubrication systems have supplied lubricating coatings to the surfaces of specific sliding and rolling mechanisms.

The authors argue that ceramic coatings can be produced with qualities superior to those of the same compound consolidated by sintering or hot pressing, at reasonable cost. They suggest that the

development of composite coatings for wear resistance and lubrication applications should be a high-priority area of future work.

This paper is recommended for a thorough review of this complex field where composite materials are finding an important role to play in the development of new technology.

References

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- [2] Hirai, T., "CVD of Si_3N_4 and Its Composites," in *Emergent Process Methods for High Technology Ceramics, The Nineteenth University Conference on Ceramic Science*, Plenum Press, New York, in press.