Summary

The technical papers presented in this book address some of the most difficult and important topics facing composites science today. These papers succeed in identifying key technical issues and providing insight and progress toward their solution. It is hoped that the numerous questions raised by the papers will serve to stimulate further research, for much remains to be done before a useful level of understanding is achieved.

One of the key differences between discontinuous high volume composites and the traditional aerospace continuous fiber systems is the control of properties through the control of fiber orientation state. The orientation of fibers in molded discontinuous fiber composites cannot be controlled well, and in most cases the orientation state changes unpredictably throughout the part. This, along with fiber distribution and overall material inhomogeneity, leads to large variability in material properties. The paper by Shirrell examines the relationship between the complex material microstructure in sheet molding compound and the variability in properties. For the R25 sheet molding compound (SMC) system, Shirrell's research showed that randomly occurring flaw sites in the material control strength. The failures observed occurred in the matrix, rarely breaking glass fibers. Additionally, a surface veil of individual fibers (that is, well dispersed and separated bundles) was manifested with a resultant increase in flexural strength. Specimens which upon microstructural analysis had the best fiber bundle separation and dispersion correspondingly had the lowest coefficients of variability. Shirrell also mentions the relationship of fiber orientation state to the measured elastic and strength properties but kept that parameter relatively constant in his studies. Denton and Munson-McGee expand upon the role of fiber orientation effects on the elastic properties of SMC and discuss a nondestructive technique for quantitatively measuring fiber orientation. The technique employs lead glass tracer fibers to "dope" the SMC so that X rays can be used to measure the in situ fiber orientation state. A high contrast photographic image of the X-radiograph is then used as a diffraction grating in a Fraunhofer diffractometer. The resulting diffraction patterns are then analyzed to quantitatively specify fiber orientation state. Since the fiber orientation state and distribution play such a key role in material property determination, the development of such a test method is extremely important.

Fiber orientation state and inhomogeneity also present some interesting challenges to the understanding of fatigue and fracture in discontinuous fiber composites. Mandell et al discuss an avoidance crack growth model, in which the crack extends by the coalescence of isolated failure zones, to predict fatigue crack growth and life trends in injection molded reinforced thermoplastics. For the materials investigated, submillimetre glass reinforced thermoplastics, a correlation was established between the model and experimental data. Fatigue crack growth was shown to follow a power law relationship, and the threshold fracture toughness values for crack growth in the composites were shown to be a higher percentage of K_{Ic} than that of unreinforced polymers or metals. Continuous fiber composites are also found in ground transportation applications, and the paper by Newaz discusses flexural fatigue behavior of E-glass/epoxy. Two distinct failure modes were identified corresponding to the deflection amplitude. High amplitude deflection produced matrix cracking, fiber breakage (tension side), and fiber buckling (compression side), resulting in rapid stiffness loss. Low amplitude deflection resulted in matrix cracking accompanied by fiber to matrix debonding on the tensile surface, causing gradual loss of stiffness. This research raises some interesting questions about the behavior of the material in a variable amplitude fatigue spectrum. The fatigue performance of composites is altered by the presence of environmental conditions. The combined effects of fatigue loading and exposure to water and *iso*octane on the fatigue life of SMC-R65 is discussed by Ngo et al. Water-soaked specimens showed about a tenfold decrease in fatigue life over dry specimens, while results for *iso*octane-conditioned specimens were inconclusive. Questions remain about the exact mechanism of property degradation caused by the liquid environment.

Bolted joint behavior in SMC-R50 is discussed in the paper by Wilson. While the strength of the joints was shown to vary with fastener diameter, torque, edge distance, and half spacing, scatter in the data makes it hard to quantitatively describe the relationship between variables. Throughout the test program, regardless of geometry, tension failure modes prevailed. Most failures were net tension, but for the large W/D specimens cleavage failures were observed. The large scatter of test data can be attributed to variable inhomogeneity in the material in combination with hole placement. The implications of this for design are far reaching and are further amplified in the paper by Gillespie and Pipes on the thermoelastic response of a cylindrically orthotropic disk. In this study on a transfer molded disk, the fiber orientation distribution was analyzed and the influence upon the thermoelastic properties described. It is shown that the molding process produces a disk with distinct layers of different fiber orientation state and that the layer thickness varies with radial position. A comparison between an analytical solution assuming homogeneous orthotropic properties and integration and finite element solutions accounting for the property variation reveals that the gross in-plane response is adequately predicted by all three methods, while there is an interlaminar free edge stress at the boundary which is accounted for only by analyses which handle the laminated structure of the disk and the radial variation in properties.

The combined effect of moisture and elevated temperature on the integrity of SMC-R65 is assessed in a paper by Hosangadi and Hahn. The paper focuses on the morphological characteristics of degradation by hygrothermal exposure, not on a quantitative assessment of property degradation. Their findings indicate that the infused water not only degrades properties by inducing mechanical strains but also by chemical mechanisms as evidenced by the examination of fluid found in blisters resulting from hygrothermal exposure.

Another important factor which influences final properties in both continuous and discontinuous composites is processing conditions. In order to optimize and develop consistant properties in high volume processes like filament winding and pultrusion, the flow and curing characteristics of the resin must be understood. Loos and Freeman present results on the influence of ply orientation on the flow characteristics of graphite epoxy laminates in their paper. They conclude that stacking sequence does not have a significant effect on the resin flow normal to the plane of the laminate, while results were inconclusive for effects on the flow of resin parallel to the plane of the laminate. The model developed by Loos and Springer applies as verified by comparison with experimental data.

If considered for structural applications, characterization of the time-dependent response of discontinuous fiber composites is necessary since the polymer matrix phase is highly viscoelastic. Yen et al characterize the viscoelastic response of an SMC-R50 material for different thermomechanical conditions. They found that the Findley equation adequately models the creep behavior and that the time exponent is independent of stress, varies linearly with temperature, and asymptotically approaches a constant value at approximately 8000 min. The results with lowest scatter were obtained by tests on conditioned specimens, a finding that has been previously reported for continuous fiber laminates by Shapery.

The final paper by Driscoll discusses the use of dynamic mechanical properties for predicting the processability and properties of plastics and composites (ASTM D 4065). The paper is in the form of an overview with case examples to explain the various test configurations and the material property parameters which can be measured using the test. Dynamic mechanical tests can be used to determine rheological parameters, viscoelastic properties, glass transition temperature, and temperature-dependent mechanical properties through shear, tension, compression, and flexural test configurations.

Composites are exciting materials because they offer the opportunity to simultaneously engineer the material and component, which if properly executed produces a degree of optimization in design not possible with isotropic materials. It is this potential which has spawned the use of composites in ground transportation and high volume consumer products. The research findings presented in this book have barely scratched the surface of knowledge which must and will be fostered in the coming years.

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