High Modulus Fiber Composites in Ground Transportation and High Volume Applications

D. W. Wilson, *editor*

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HIGH MODULUS FIBER COMPOSITES IN GROUND TRANSPORTATION AND HIGH VOLUME APPLICATIONS

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on High Modulus Fibers
and Their Composites
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Foreword

The symposium on High Modulus Fiber Composites in Ground Transportation and High Volume Applications was held in Pittsburgh, Pennsylvania on 7 Nov. 1983. ASTM Committee D-30 sponsored the symposium. D. W. Wilson, University of Delaware, Center for Composite Materials, presided as symposium chairman. D. L. Denton, R. E. Evans, C. D. Shirrell, and S. S. Wang presided as session chairmen.

Related ASTM Publications

Long-Term Behavior of Composites, STP 813 (1983), 04-813000-33

Analysis of the Test Methods for High Modulus Fibers and Composites, STP 521 (1973), 04-521000-33

Effects of Defects in Composite Materials, STP 836 (1984), 04-836000-33

A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

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Introduction

The conference on High Modulus Fiber Composites in Ground Transportation and High Volume Applications focused on a very important issue in composites technology, the relationship between processing, material microstructure, and the resulting material properties. Material formulations and processing techniques employed in the high volume manufacturing of composite components produce complex microstructure, but without control. The design of material microstructure, especially fiber orientation state, forms the basis for effective composites utilization, and ineffective control of microstructural parameters increases property variability and forces poorly optimized designs. Ultimately, high volume processes need to be developed which allow design and control of material properties during processing.

The first steps toward this goal are to understand the relationship between processing parameters and material microstructure and to be able to quantitatively measure and describe microstructural features which determine the macroscopic material properties. The relevant microstructure parameters which control composite properties are the constituent properties, volume fractions of constituents, interfacial adhesion between the phases, fiber orientation state, fiber aspect ratio, void content, state of resin cure (thermosets), and resin crystallinity (thermoplastics). In two-phase, continuous fiber aerospace composites aspect ratio and fiber orientation are highly controlled. Composites for high volume applications are often discontinuous fiber, three-phase systems in which fiber aspect ratio and orientation state are not controlled. The control of these two parameters and understanding the effects of their distribution on properties is a central problem in the effective use and fabrication of high volume composite materials.

The intent of the conference was to provide a forum for discussing the macroscopic behavior of typical high volume composite material systems, materials characterization methods, and the relationship between processing and material properties. The knowledge developed in these areas will form the foundation for the ultimate objective, design and control of composite properties.

The papers published in this volume address these primary topics along with more advanced property characteristics such as environmental sensitivity, fatigue behavior, and viscoelastic response. The identification and systematic research of the complex topics addressed in this volume is embryonic. It is hoped that the reported research findings will serve to stimulate new, broader based research activities in this important area of composites technology.

D. W. Wilson

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C. David Shirrell[1]

The Influence of Microstructural Variability upon the Scatter in Mechanical Properties of R25 Sheet Molding Compound

REFERENCE: Shirrell, C. D., **"The Influence of Microstructural Variability upon the Scatter in Mechanical Properties of R25 Sheet Molding Compound,"** *High Modulus Fiber Composites in Ground Transportation and High Volume Applications, ASTM STP 873*, D. W. Wilson, Ed., American Society for Testing and Materials, Philadelphia, 1985, pp. 3–22.

ABSTRACT: The large scatter in the static strengths of R25 sheet molding compounds was observed to be related to the variability in the complex microstructure of this material. This microstructure consists of a subsurface veil of individual glass fibers and an internal core of intact fiber glass bundles.

KEY WORDS: sheet molding compounds, discontinuous composites, composites variability, composite microstructure

Short, chopped glass fiber reinforced sheet molding compound (SMC) is moving into its second generation of mass automotive applications. Previously, the use of this material has been limited (in large volumes) to nonstructural, appearance components such as front end header panels. In the newer second generation applications, SMC will be used in lightly stressed structural components (such as tailgates and body panels) [*1,2*]. Future design developments using this material in highly stressed major automotive components may lead to a third generation of SMC applications.

These more demanding second and third generation structural applications of SMC are placing increased emphasis on the elimination of the large mechanical property variability found in this material. Previous work in the composites literature has documented that this material has scatter in its mechanical properties as large as 40% even when such obvious material defects as weld lines and gross anisotropic glass fiber orientation have been eliminated [*3,4*]. While this

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scatter in mechanical properties can be accurately described by empirically derived Weibull statistical parameters, simple probabilistic flaw site models do not correctly predict the observed mechanical property variability in this material [*4*].

Thus, the nature of the flaw site(s) that leads to the large scatter in mechanical properties of SMC remains unknown. In an attempt to partially resolve this issue, the microstructures of three different R25 (25% by weight randomly oriented glass fibers) SMC materials were examined in detail, and this paper will discuss those results and their relevance to the scatter in mechanical properties of SMC.

Experimental Procedures

Material Fabrication

The details of the three R25 SMC compositions used in this study have been described previously [*4*]. Two of these materials utilized isophthalic polyesters as their resin matrix, while the third was formulated with a vinyl ester resin matrix. All of these SMC materials were molded in the form of flat plaques with dimensions 533 by 610 by 3.4 mm (21 by 24 by 0.13 in.). The molding procedure consisted of charging approximately 2000 g (4.4 lb) of the uncured SMC material into the center of a compression die preheated to 138°C (280°F) and applying a pressure of 5.5 MPa (800 psi). The SMC was held at these conditions for 120 s to complete the cure of the plaque.

Specimen Fabrication

These cured plaques of SMC materials were cut into ASTM Method for Tensile Properties of Plastics (D 638-82a) Type 1 tension specimens, ASTM Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating (D 790-81) flexure specimens, and 25.4 by 25.4 mm (1 by 1 in.) density and burn-out specimens on a water-cooled diamond saw using the procedures which have been previously described [*4*].

Experimental Procedures

Density, resin content, filler content, and fiber content of the SMC materials were determined from each of the panels used in this study. The results of these tests can be found elsewhere [*4*].

Mechanical Testing Procedures

Prior to mechanical testing, all tension and flexure specimens were weighed and then maintained at 63°C (145°F) and 0% relative humidity until they reached a constant weight. The specimens were then tested at room temperature (≈21°C) in either uniaxial tension, three-point flexure, or four-point flexure on an Instron Universal Test Machine using the procedures described in either ASTM Method

for Tensile Properties of Plastics [Metric] (D 638M-81) or ASTM Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating (D 790-81) (Method I and II). The flexure specimens were tested using an L/d (span/depth) ratio of 16 to 1. Tension specimens which did not fail in the gage area (fracture site index numbers greater than 7.5 and less than 14.5) were deleted from the tensile data.

Results and Discussion

Statistical Aspects of SMC Strengths

The variability in mechanical properties of SMC is substantial. One of the polyester resin SMCs used in this study has coefficients of variation in mechanical properties which are as large as 18% (Table 1). As indicated in Fig. 1, the specimen orientation does not appear to significantly influence this mechanical property variability. (For brevity, only the data from one SMC material will be presented in this paper. Unless otherwise noted, the other SMC materials examined in this study exhibited similar results.) Thus, gross fiber anisotropy can be eliminated as a source of the mechanical property scatter in these plaques.

TABLE 1—*Strength (σ) and modulus (E) of R25 SMC.*[a]

Mechanical Property		Statistical Measure[b]		
		Average	Standard Deviation	Coefficient of Variation, %
		POLYESTER TYPE I		
Tensile	σ	48.8	9.1	18.6
	E	11.7	1.2	10.3
3-point flex	σ	131.9	19.4	14.7
	E	10.5	0.5	4.8
4-point flex	σ	116.9	21.1	18.0
	E	14.2	1.2	8.5
		POLYESTER TYPE II		
Tensile	σ	56.2	6.9	12.3
	E	14.1	1.5	10.6
3-point flex	σ	156.1	22.5	14.4
	E	13.9	0.7	5.0
4-point flex	σ	137.2	18.3	13.3
	E	15.5	0.9	5.8
		VINYL ESTER		
Tensile	σ	96.0	8.6	9.0
	E	13.7	1.2	8.8
3-point flex	σ	216.6	29.1	13.4
	E	14.3	0.9	6.3
4-point flex	σ	159.6	18.0	11.3
	E	16.4	0.6	3.7

[a]Strength in MPa and modulus in GPa.
[b]The number of replicates ranged from 22 to 39.

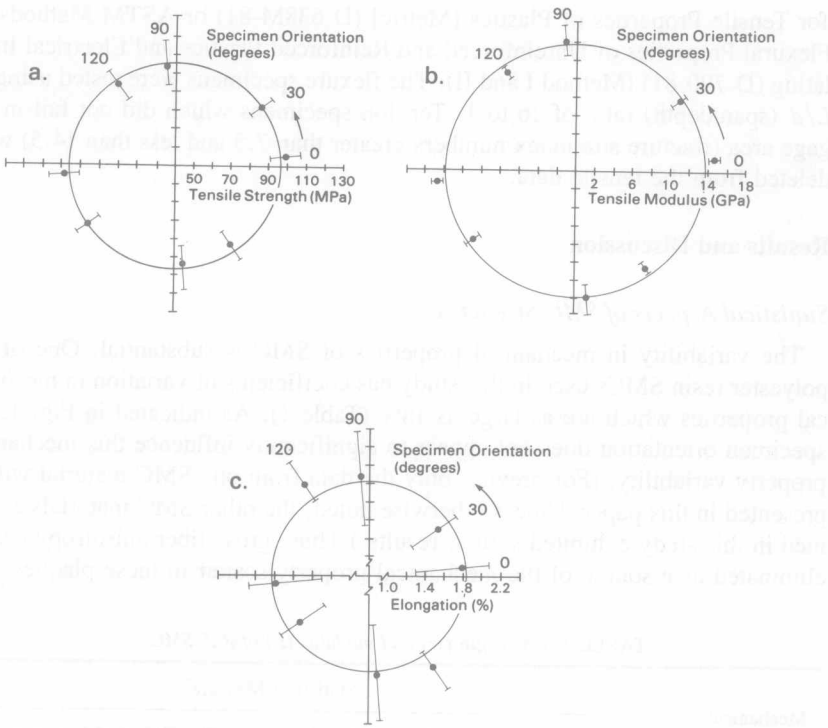

FIG. 1—*Polar diagram of specimen orientation versus tensile properties for the vinyl ester SMC: (a) strength, (b) modulus, and (c) elongation.*

In Fig. 1, the average value of six replicates per orientation is indicated by a dot. The scatter band represents the range of the data. For these polar plots, a deviation from a perfect circle, which has a radius equal to the average property value, represents a variation in mechanical properties with specimen orientation. The observed variability in mechanical properties of this material is also not due to gross variations in either void content, resin content, filler content, or fiber content of the SMC plaques used in this study [*4*].

Rather, the source of the mechanical strength variability in SMC materials appears to be randomly occurring internal material flaws. Previous work [*4*] has shown that Weibull statistics can provide a useful technique for quantifying and interpreting the nature of these material flaws in R25 SMCs. One of the Weibull strength distributions for the vinyl ester SMC examined in this study is given in Fig. 2. As discussed in Ref *4*, it is possible to calculate the Weibull strength distribution using theoretical flaw site models. Figures 3 and 4 illustrate that these theoretical flaw models, based on random flaws distributed in either the surface, volume, or edge of the SMC mechanical specimens, do not predict the experimentally observed results.

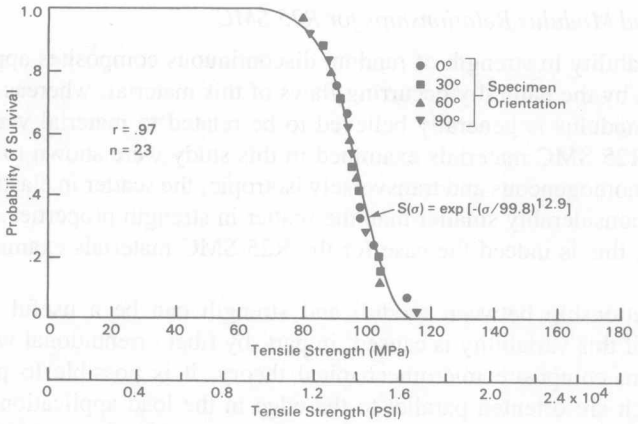

FIG. 2—*Weibull tensile strength distribution for the vinyl ester SMC.*

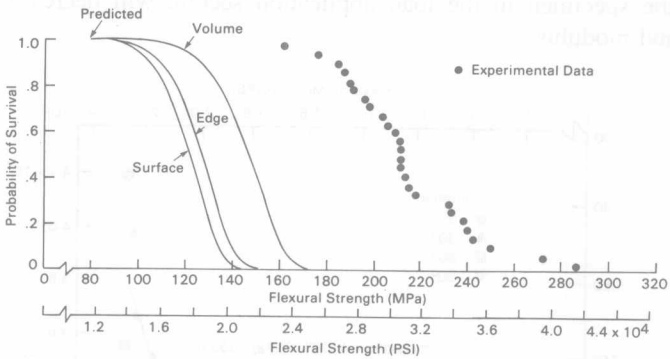

FIG. 3—*Calculated three-point flexural strength distributions for the vinyl ester SMC.*

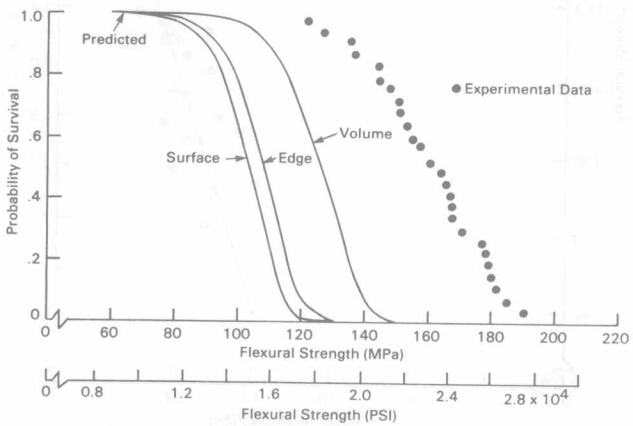

FIG. 4—*Calculated four-point flexural strength distributions for the vinyl ester SMC.*

Strength and Modulus Relationships for R25 SMC

The variability in strength of random discontinuous composites appears to be determined by the naturally occurring flaws of this material, whereas the scatter in elastic modulus is generally believed to be related to material variation [*5*]. Since the R25 SMC materials examined in this study were shown to be macroscopically homogeneous and transversely isotropic, the scatter in elastic modulus should be considerably smaller than the scatter in strength properties. As shown in Table 1, this is indeed the case for the R25 SMC materials examined in this study.

The relationship between moduli and strength can be a useful method to determine if this variability is caused, in part, by fiber orientational variations in SMC. From composite micromechanical theory, it is possible to predict that fibers which are oriented parallel to the edge in the load application section of three- and four-point flexure specimens will substantially increase both the specimen's strength and modulus [*6*]. Those fibers which are oriented transverse to the edge of the specimen in the load application section will decrease both the strength and modulus.

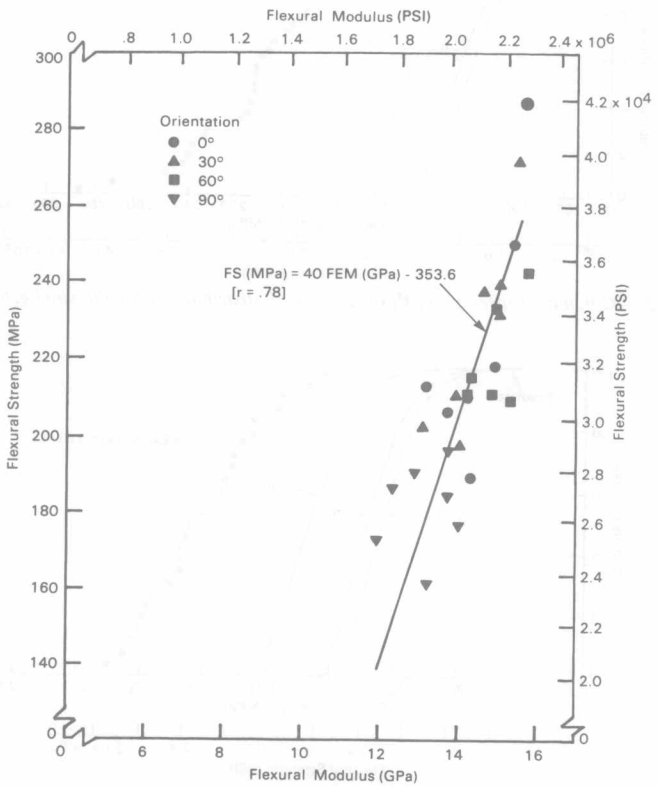

FIG. 5—*Three-point flexural strength versus flexural moduli for the vinyl ester SMC.*