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Thermal and mechanical anisotropy in compression molded carbon fiber/resin composites

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In this paper, molding compounds are subjected to uniaxial deformation in a rectangular mold, and several different mechanical parameters such as tensile strength were measured. The main goal of these experiments were to demonstrate that nonintrusive thermal conductivity probes could be used to material testing due to its ability to correlate to strength. This is a useful concept for our project, and might be a correlation we ourselves could make it the post processing of our data. The acquired data trends can then be compared with future compression molded parts, and strength could be then predicted. The paper also analyzes how shear forces can rotate fibers out of their respective plane, and how this can effect tensile strengths. This is another important concept for manufacturing carbon fiber parts, and understanding its effects is an important consideration.

Previous work done with unidirectional glass fibers in epoxy showed that thermal conductivity was correlated with tensile modulus, and through thermal conductivity testing the tensile strength could be determined. In this paper, thermal and mechanical anisotropy is examined for carbon fiber/resin composites prepared by sheet compression molding. These molding compounds are subject to uniaxial deformation in a rectangular mold over a range of strain states. Mechanical properties such as tensile strength in axial and transverse directions, thermal conductivity (t.c.) in all directions, and in-plane fiber orientation were all tested. Through this data, the possibility of using a noninvasive thermal conductivity test to measure tensile strength was then discussed.

Before the molded material is pressed, an analytical method is devised to estimate the internal strain pattern. This model is created by simplifying the equations of motion for the squeezing flow in the compression molder, relating that to shear stress, and then performing an integration with no-slip boundary conditions. The resultant equations allow for a computation of the velocity profiles within the SMC "charge" (molding compounds) for different axial positions along the draw axis at start of compression.

Following this prediction, the sheet compression molded (SMC) samples were molded in a rectangular cavity that is 25 cm by 15 cm, equipped with heaters and thermocouples. The molding material was commercial grade (AMC-8590) and carbon fibers were chopped polyacrylonitrile (PAN) fibers. Another set of material was tested, a lab-prepared compound consisting of chopped fibers in room-temperature curing epoxy resin (S-CFP series)

Tensile testing and thermal measurements testing were performed on both molding materials. Axial tensile strength increased 42% from draw ratio (DR) 1 to DR 2 and continued increased up to DR 8, while transverse tensile strength increased only slightly. Axial thermal conductivity rose 32% from DR 1 to DR 2, then decreased at DR 4 and DR 8, while the general trend for normal thermal conductivity (t.c) showed moderate decrease while values for the transverse t.c. showed no trend. The t.c. measurements showed higher variability than strength measurements due to much smaller cross-sectional area being measured as opposed to the tensile measurements. T.c. values more closely correlated with tensile strength for the S-CFP composites as opposed to the AMC-8590 composite. Orientation measurements were also attained, and the Hermanns' orientation parameter calculated. The AMC-8590 material had significantly higher orientation than did the S-CFP material. Degree of orientation increased with draw ratio, with core region values being higher than surface values.

The ratio of shear orientation and extensional (x-directed) orientation effects can be obtained by differentiation of the previously established mathematical models. This ratio tends to infinity at mold surfaces and tends to zero at the SMC sheet mid-plane. The shearing flow orienting effect (x-dir) is max at the mold surfaces and zero at the sheet mid-plane. The extensional flow orienting effect is zero at the surfaces and maximum at the sheet mid-plane. Surface shear flow exerts a high rotational influence (about the y-axis) which increases with x, and this rotation can cause fiber buckling breakage. Previous research described such behavior in glass fiber/epoxy vinyl ester composites sheets prepared in the same manner as this experiment. The behavior of the samples tested in this paper are consistent with this interpretation, but fiber breakage was not observed, most likely due to the superiority in strength of carbon fibers over glass fibers. The differences in surface and core orientation are attributed to the rotational effect, forcing fiber ends to rotate from the x-y plane into the z direction. Thus, axial direction t.c. and tensile strength are limited by this rotation, which increases with DR.

In conclusion, the study showed that tensile strength increases in the draw direction in uniaxial SMC molding, but the increase is limited due to surface shear orientation effects. Axial direction thermal conductivity showed a similar trend but is more affected by orientation of the fibers. Finally, thermal conductivity was shown to correlate with tensile strength in the tested directions (axial and transverse), showing the possibility that non invasive thermal conductivity measurements can be used to predict tensile strengths.