IMPACT-TOLERANT SMC RESINS FOR DEMANDING STRUCTURAL APPLICATIONS

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Abstract

Composite materials have penetrated the transportation market where their lower total component cost and lighter weight have made them the material of choice. As designers and engineers become more comfortable with the use of composites, they are being specified in more demanding, load-bearing applications. Structural thermoset resins combine high modulus, the ability to efficiently translate reinforcing fiber properties, with the elasticity to withstand the high stresses and strains of load bearing applications. A new generation of impact-tolerant structural thermoset resins has been developed that have the high modulus critical to achieving maximum structural properties, yet exhibit the toughness of thermoplastics. These tough, thermosetting resins absorb high transient loads without suffering micro-structural damage that can propagate to failure after repeated mechanical, chemical and environmental exposures. Cast resin properties, and reinforced composite properties show the potential of these materials as a cost-effective option for transportation applications. Efficiency of reinforcing fiber utilization allows weight reduction without sacrificing structural performance. These new, impact-tolerant materials can be processed with standard techniques at the production rates typical of high volume processes such as SMC at very low scrap rates. Composite formulation latitude allows tailoring the mechanical, dimensional and appearance properties that typically make composite materials an economically attractive choice.

Background

Conventional sheet molding compounds (SMC) have a reputation for brittleness, in contrast to urethane-based polymer composites for structural reaction injection molding (SRIM). Newly developed Dion® ITP two-component hybrid polymers for SMC marry the best mechanical attributes of urethane polymers with the ease of processing and formulating flexibility of conventional SMC, typically based on unsaturated polyester or vinyl ester resins. We show that these urethane-hybrid polymers, (UHP) can be a good choice for structural components with a broad range of properties owing to the UHP's compounding flexibility—tailored glass & mineral filler contents, glass fiber lengths, dimensional control with conventional low-shrink and low-profile additives, pigments, compression/injection mold flow properties and cure-speed behavior.

Experimental

Materials

We evaluated both neat resin and reinforced, compression-molded compositions using a number of different UHP's, labeled "A", "B" and "C" that were thickened with an isocyanate pre-polymer. Aside from the UHP's, molding compound formulations contained materials typical for conventional SMC: chopped fiber glass rovings, mineral fillers (kaolin, $CaCO_3$), thermoplastic low-shrink & low-profile additives, pigments, internal mold release agents and peroxide curing agents.

Processing

We produced SMC with a 1-meter wide Finn & Fram machine. After allowing for thickening, flat panels were compression molded for 3-minutes at 3.45 MPa (500 psig) in a 355x355 mm square, chromed tool heated to 150°C.

Testing

Standard test methods were used to determine mechanical properties at 25C with an Instron servo-mechanical tester. A Perkin-Elmer Thermal Mechanical Analyzer (TMA) measured the coefficient of thermal expansion (CTE).

Results & Discussion

Toughness—Neat Resin

For a neat thermoset resin, the most relevant property that illustrates toughness is the fracture behavior according to ASTM D-5045. Figure 1 shows the specimen configuration for a single-edge, notch bend (SENB) test. K_{1c} is the energy per unit area necessary to propagate a crack, or critical stress intensity factor. Higher values indicate better resistance to fracture failure. Comparing a conventional vinyl ester resin to two different UHP's—"A" and "B"—there's a striking difference in fracture toughness. Fracture toughness for UHP's are 2~3 times higher than a Bisphenol-A epoxy vinyl ester resin. With such high values, UHP's fit well with structural applications such as composite truck boxes that must endure repeated impact loads.

Thermo-mechanical Properties—SMC

To demonstrate the formulating flexibility of UHP's we made SMC with a range of chopped fiber glass roving weight fractions from 0 to 60%. Molded panel thermo-physical properties are shown in Table I, along with comparison against some traditional SMC materials. UPH-C was converted into a range of 0 to 10% by weight chopped glass SMC, while UPH-A spanned the higher range from 40 to 60% glass fiber.

Before going into a comparison, it's worth noting that 0 to 10% glass SMC in thin moldings at 1.8 mm thickness does not exist in the market today. Owing to the tremendous toughness & strength of UPH-C relative to standard unsaturated polyester SMC resins, allows the formulating window to expand to unusually low glass fiber levels <10%. If we attempted to mold thin panels with very low to zero glass content SMC made with conventional unsaturated polyester resins, the parts would shatter during molding or demolding.

Comparing conventional SMC versus the low-glass, high-filler series of compounds based on UPH-C, there are number of differences. First, at 11.4% glass in UPH-C-based SMC the shrinkage, strength, stiffness, and CTE properties are nearly equal to conventional, low-shrink SMC with roughly twice as much glass fiber content (21%). Tensile elongation, however, is 3x times higher for the UPH-C SMC at 11.4% glass. Using the toughness indicator computed from the area under the tensile stress-strain curve, toughness too is 3xtimes higher for UPH-C SMC at 11.4% glass. Note that none of the low-glass, high-filler SMC examples sacrifices stiffness: Young's modulus averages 14 GPa, just like conventional SMC. Specific modulus too is nearly equal, so part design constraints that hinge on deflection could be be made more impact resistant using UHP-C.

Another notable characteristic of the UHP-C SMC formulations is the high T_g, or glass transition temperature. Using dynamic mechanical analysis, we measured the T_g of both urethane-hybrid SMC compounds. Typical rules of polymers dictate that raising T_g lowers elongation and impact properties. At 150°C, the T_g is very high for a tough, high-elongation composite, and falls in the range of conventional SMC that must endure ELPO paint bake cycles at 190°C.

The final set of urethane-hybrid SMC data falls in the 40 – 60% chopped glass content range, consisting of a different polymer, UPH-A. As expected, flexural and tensile strength properties increase. Shrinkage rates approach zero for all three glass contents. Most intriguing is the increase in tensile elongation as the glass content increases. At 2.0% elongation for the 60% glass SMC, toughness measured by the stress-strain curve integration method, is exceptionally high due to a combination of three favorable factors: high elongation, stiffness and strength.

Analyzing the elongation properties of both the low-glass, high-filler UHP-C SMC and the high-glass, low-filler UHP-A SMC, interesting relationships appear. In Figure 3, the elongation is plotted as a function of glass content. Linearity within the two sets of data is surprising, and then there's a step change from one set to the next.

Conclusion

New hybrid polymer resins for SMC have been developed for impact-resistant applications. Molding and processing properties match conventional SMC based on unsaturated polyester resins, but there are big gains in toughness and strength. These improvements increase the chances of success for lightweight, cost-effective, structural components.

Tables & Figures

Table I: Physical Properties of Conventional and UHP-Based SMC

Property	Units	Conventional SMC 1.8 mm Part		Low-Glass, High Filler SMC 1.8 mm Flat Panel UHP-C			High Glass, Low Filler SMC 2~3 mm Flat Panel UHP-A		
		Zero-Shrink	Low-shrink	No Glass	Low Glass (5%)	Low Glass (10%)	Med Glass (40%)	Med Glass (50%)	High Glass (60%)
Glass Content	Wt%	22	21	0	5	11	43	50	60
Density	g/cm^3	1.86	1.80	1.86	1.85	1.89	1.69	1.72	1.80
Shrinkage	mm/m	0	1 – 3	7 – 8	2 – 3	2 – 3	1	0 – 1	1
Flexural Strength	MPa (psi)	100.7 (14,600)	78.0 (11,310)	55.2 (8,010)	90.2 (13,080)	121.9 (17,680)	347.4 (50,390)	380.8 (55,230)	442.0 (64,100)
Flex Modulus	GPa (kpsi)	8.00 (1,160)	10.00 (1,450)	12.2 (1,770)	10.07 (1,460)	12.55 (1,820)	16.20 (2,350)	16.62 (2,410)	19.10 (2,770)
Tensile Strength	MPa (psi)	64.5 (9,530)	40.1 (5,820)	33.1 (4,800)	23.4 (3,400)	35.8 (5,190)	137.7 (19,970)	210.9 (30,590)	226.7 (32,880)
Tensile Modulus	GPa (kpsi)	15.2 (2,210)	14.3 (2,070)	13.9 (2,010)	13.5 (1,960)	14.3 (2,080)	13.7 (1,980)	16.3 (2,370)	21.4 (3,100)
Elongation	%	0.8	0.5	0.3	0.9	1.5	1.5	1.8	2.0
Glass Transition	°C	---	---	150	150	150	120	120	120
Thermal Expansion Coefficient	e^{-06}/°C	16.8	31.6	25.7	25.7	26.0	---	---	---

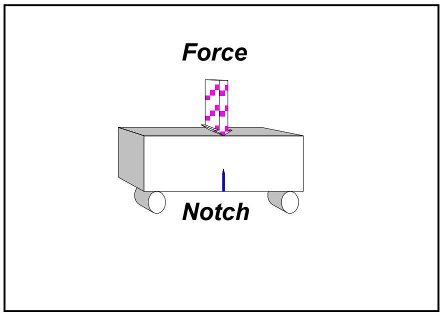

Figure 1: Fracture Toughness Test Specimen Configuration for ASTM D-5049 Single-Edge-Notch-Bend (SENB) test method.

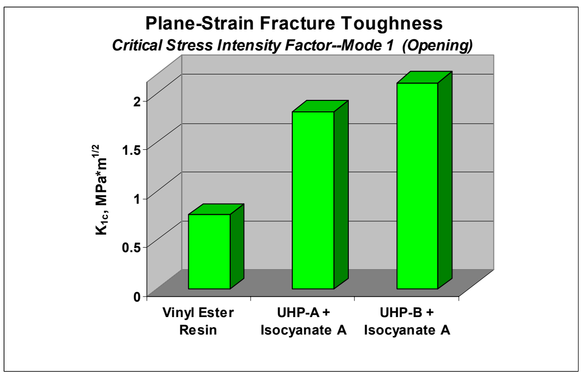

Figure 2: Comparison of K_{1c} fracture toughness for neat resins using ASTM D-5049 SENB test method.

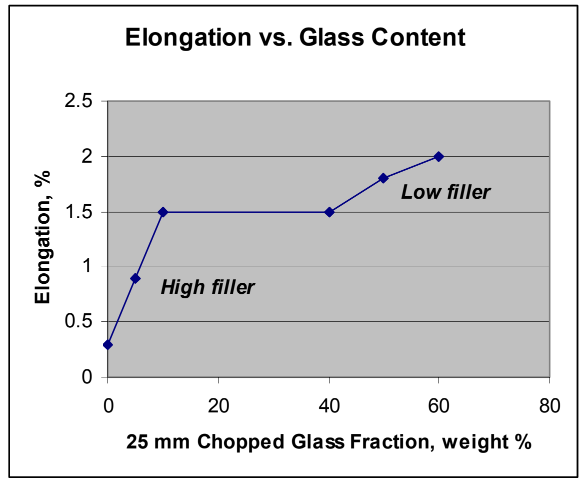

Figure 3: Tensile elongation of SMC over a range of chopped glass contents, and two extremes of mineral filler content—high and low.