

Mississippi Pultrusion

Pultrusion Research Report of The University of Mississippi
Composite Materials Research Group

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Recent Publications

K. S. Raper, J. A. Roux, J. G. Vaughan, and E. Lackey, "Permeability Impact on the Pressure Rise in a Pultrusion Die," *Journal of Thermophysics and Heat Transfer*, Vol. 13, No. 1, 1999, pp. 91-99.

Brief Abstract: In this study, three permeability models are employed to investigate their effect on the pressure rise in the pultrusion die inlet. A numerical model, based on Darcy's law for flow in a porous media which employs the finite volume solution method, is developed to predict the pressure and velocity fields in the pultrusion die.

J. A. Roux, J. G. Vaughan, R. Shanku, E. S. Arafat, J. Bruce, and V. R. Johnson, "Comparison of Measurements and Modeling for Pultrusion of a Fiberglass/Epoxy I-Beam," *Journal of Reinforced Plastics and Composites*, 17 (17), 1998, pp. 1557-1579.

Brief Abstract: This research presents the experimental characterization and modeling of three-dimensional unsteady-state temperature and degree of cure distributions for the pultrusion manufacturing of fiberglass/epoxy I-beam composites. The model is capable of predicting temperature and degree of cure distributions for composites with Cartesian shapes in three dimensions and temperature profiles in pultrusion dies without the aid of predetermined temperature values used as die wall boundary conditions.

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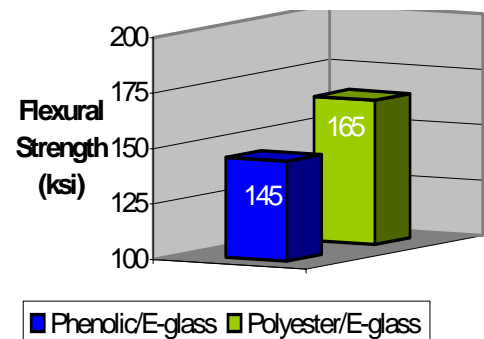
CMRG Researchers Team with Georgia Pacific to Characterize New Phenolic Pultrusion Resins

Researchers at the Composite Materials Research Group (CMRG) at the University of Mississippi (UM) have recently been involved in a research study designed to characterize new phenolic pultrusion resins under development by Georgia Pacific. Phenolic resins examined in this study include GP-5008, GP442D35, and GP-652D79. Results from this study indicate that these phenolic resin systems overcome many of the limitations that traditionally have been associated with the pultrusion of phenolic resin systems.

Phenolics are known to offer desirable properties such as excellent fire, smoke, and smoke toxicity properties; the retention of properties after long-term exposure to high temperature; excellent electrical resistance; and excellent chemical resistance. Although they offer many desirable properties, in the past, phenolic resin systems have received limited attention by the pultrusion industry because phenolic resins that were available were often difficult to pultrude. Due

to the chemistry of the condensation reaction of phenolic resins, vapors and water are given off in the die. Early generations of phenolic resins typically had short pot life, high viscosity, slow cure rate, and poor handling characteristics. Georgia Pacific has developed a new generation of phenolic resins which overcome a number of the limitations traditionally associated with phenolic pultrusion. Phenolic pultrusion research experiments conducted by the CMRG have characterized the effects of a variety of process parameters necessary for the successful pultrusion of this new generation of phenolic resins.

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Example showing the comparable mechanical properties of a phenolic/E-glass pultrusion and a polyester/E-glass pultrusion.

CMRG Research Profiles

The Composite Materials Research Group at the University of Mississippi emphasizes an interdisciplinary research approach. Presently, the research is divided into four main areas — micromechanics modeling, static and dynamic mechanical and physical property characterization, thermal and kinetic modeling, and experimental characterization/optimization. In this issue of *Mississippi Pultrusion*, recent research concerning the effect of fillers on the properties of pultruded

Effect of Pultrusion Fillers on Mechanical and Physical Properties of Pultruded Composites

composites is presented.

While selection of an appropriate resin is critical for the pultrusion of quality products, additives which are combined with the neat resin to formulate the final mix should not be overlooked. Fillers are typically included in pultrusion resin mixes, but few studies have examined their effect in pultrusion. Pultrusion fillers, however, do not just serve as inexpensive space-filling materials. Materials used as fillers in pultrusion resins also aid in die compaction, influence resin viscosity, affect processability of the resin system, affect composite surface appearance, and influence mechanical properties. The objectives of this study were to enhance understanding of the influence of pultrusion fillers and provide data that can be used to select the appropriate filler to use in conjunction with pultrusion resins to produce desired properties.

Pultrusion experiments were conducted using the seven fillers (ASP400P, ASP600, ASP 900P, Camel

Wite, ATH, CHC, and Translink 37). These fillers differ in properties such as composition, mean particle size, pH, and brightness. In order to evaluate the influence of fillers with different types of resins, pultrusion experiments were conducted using the EPON® Resin 9500/EPI-CURE® Curing Agent 9550 epoxy resin system and the AOC E606-6 polyester resin system. For the epoxy runs, die temperatures of 340°F, 370°F, 370°F and a pull speed of 18 inches/minute were used. For the polyester runs, die temperatures of 282°F, 327°F, 318°F and a pull speed of 24 inches/minute were used. A total of 14 pultrusion experiments were conducted. A filler loading of 20 phr was used as a nominal condition, but filler loadings at 10 and 5 phr were also examined. For each experiment, a 1" x 1/8" rectangular profile reinforced with nominal 68 vol. % unidirectional E-glass was pultruded on the CMRG's PTI-804 pultruder using an open-bath wet-out system. During the pultrusion experiments, pull force and sample appearance were monitored in order to characterize processability of each resin mix. Viscosity measurements were also taken during the course of the pultrusion runs.

Mechanical and physical property measurements were conducted on samples from resin castings and samples from the pultruded composites. Tests conducted on samples from the resin castings included T_g , flexural strength and modulus, tensile strength, dielectric strength, and specific gravity. Tests conducted on samples from the pultruded composites included brightness, specific gravity, T_g , short-beam shear strength, flexural strength and modulus (room temperature and 66°C), and flexural fatigue. Pultruded samples were also subjected to 150°F water immersion conditioning to determine the effect of water immersion on the durability of these different filled composites.

In general, the results of the various experiments

Properties of Epoxy Resin System Pultruded Composites

	ASP 400P	ASP 600	ASP 900P	Camel Wite	CHC 94	Translink 37	CHC 94 (10)	ATH (5)
Grey Scale Brightness (Black 0-256 White)	106	111	109	127	107	121	100	122
Short-beam Shear Strength (ksi)	7.8	8.3	7.7	7.4	7.9	7.9	7.1	6.7
Three-Point Flexural Strength (ksi)	169	176	174	160	172	110	177	178
Three-Point Flexural Fatigue (# of cycles – thousands) -60 to -235 lbs force	204	>950	>950	140	186	1.2	474	52
-45 to -295 lbs force	18	130	144	12	20	-	26	10

Properties of Polyester Resin System Pultruded Composites					
	ASP 400P	ASP 600	ASP 900P	Camel Wite	CHC 94
Grey Scale Brightness (Black 0-256 White)	153	151	147	162	154
Short-beam Shear Strength (ksi)	5.5	5.2	5.0	5.3	4.7
Three-Point Flexural Strength (ksi)	161	171	163	143	139
Three-Point Flexural Fatigue (# of cycles – thousands) -60 to -235 lbs force	24	152	240	10	28

show only minor differences in the static mechanical and physical property performance dependent on filler. The brightness of the Camel Wite pultruded composite was definitely brighter than any of the other composites, but not by large values. Viscosities of the different filled systems do differ, but not by large amounts. Static three-point flexural strengths and short-beam shear strengths vary with the type and amount of the filler used, but again not by large amounts. There are some exceptions, such as the high viscosity and low flexural strength of the Translink filled composites compared with the other fillers examined, but there were no major unexpected differences observed for the static mechanical and physical properties examined

However, there was a large difference observed in the fatigue strength of these filled products. Here, variations of over an order of magnitude were observed in the fatigue lifetime; fatigue lifetime was determined by the number of cycles required for a 25 percent reduction in flexural modulus. The ASP 900P and ASP 600 clay filled pultrusions were by far the best products. The CHC, ASP 400P, and Camel Wite filled composites were better than the Translink 37 filled systems but still were almost an order of magnitude poorer in fatigue life. There was no apparent relationship between static flexural properties and the fatigue properties. The small particle size ASP kaolin clays produced the best fatigue lifetime results; however, as shown by other property comparisons, particle size is not the only factor important in establishing the effect that fillers have on the mechanical and physical properties of pultruded composites. More studies are warranted to establish a predictive model for determining the properties of filled pultruded resins.

The environmental response of pultruded composites manufactured using various fillers has also been examined. In this environmental study, the composites were immersed in 150°F water, and three-point flex

tests and short-beam shear tests were conducted periodically over a span of 42 days. At the end of this period, additional samples were removed from the water bath and placed under vacuum to remove the absorbed water before testing. Results from this study indicate that fillers used in pultrusion resins do influence the environmental response of pultruded composites. Data from this study suggest that both the type and amount of filler used with a given resin system contribute to the response of a composite to its environment.

In this environmental study, it was observed that all of the composites were not equally affected by the hot/wet environment. For example, in the as-pultruded condition, designated as zero days of moisture exposure, the flexural strength of the epoxy/Translink 37 composite was significantly lower than the flex strength of the composites produced using the other fillers. However, after 42 days exposure, the epoxy/Translink 37 samples showed the least detrimental effects from the hot/wet environment. The epoxy/Translink 37 samples showed only a 12% reduction in flexural strength after 42 days compared to 30-45% reduction for the composites containing the other fillers. When the epoxy/Translink 37 samples were subjected to vacuum after the hot/wet exposure, flex strength comparable to the as-pultruded flex strength was observed. This type of behavior in which the composite fully recovered its original properties after exposure to vacuum was not observed for composites containing any of the other fillers. All composites did, however, demonstrate some recovery of flexural strength after vacuum exposure following the 42 days of hot/wet exposure. It is believed that the hydrophobic nature of the Translink 37 filler is linked to the unique response seen for the epoxy/Translink 37 composites.

Additional details concerning these studies are available in the *ICE '99 Proceedings of the Society of the Plastics Industry* and the *Composites '99 Proceedings of the Composite Fabricators Association*.

Recent Publications (cont.)

D. Sharma, T. A. McCarty, J. A. Roux, and J. G. Vaughan, "Fluid Mechanics Analysis of a Two-Dimensional Pultrusion Die Inlet," *Polymer Engineering*, Vol 38 (10), 1998, pp. 1611-1622.

Brief Abstract: In this study, the change in fluid resin pressure rise as a function of die entrance geometry is investigated by developing a finite element model based on the assumptions of Darcy's law for flow in porous media. The momentum equations are combined with the continuity equation to save computational time and memory. A Galerkin weighted residual based finite element method is developed to solve the resulting equation. This model is capable of predicting the pressure rise in the tapered inlet region of the pultrusion die as well as the straight portion of the die.

D. Barpanda and P. R. Mantena, "Effect of Hybridization on the Creep and Stress Relaxation Characteristics of Pultruded Composites," Vol. 17, No. 3, 1998, pp. 234-249.

Brief Abstract: This research focuses on the evaluation of creep and stress relaxation performance characteristics of pultruded glass-graphite/epoxy hybrid composites. The dynamic mechanical analysis technique was adopted for the accelerated creep and stress relaxation testing. The time-temperature superposition principle, which greatly reduced the experimental time, was effectively utilized for predicting the creep and stress relaxation properties of the hybrid composites. Results indicate that the type and amount of fiber as well as their lay-up sequence plays a significant role in determining the flow and load bearing characteristics.

Phenolic Pultrusion (cont.)

Results from the current research project have identified critical levels for a variety of parameters such as release agents, processing temperatures, and reinforcement requirements necessary for the successful pultrusion of these resin systems.

When appropriate die temperatures, release agents, and reinforcements are utilized, these phenolic systems provide pultruders a viable alternative to polyester, vinyl ester, or epoxy resins. The Georgia Pacific phenolic resins examined in this study can be processed using standard pultrusion equipment. Viscosities in the range of 1500 – 8000 cps are available, and processing speeds in the range of 12 – 30 in/min can be achieved. The resins can be successfully pultruded with or without fillers. The use of phenolic compatible reinforcements specially developed for a given resin system provides the best combination of processability and mechanical

properties for the composites. Ventilation is required to eliminate the vapors from the condensation reaction during processing, but relatively low levels of porosity can be achieved. Void densities in the range of 2 – 5% were achieved for phenolic pultrusions in this study. Room temperature mechanical properties of the phenolic composites were in the polyester to vinyl ester range. Also, with the selection of the appropriate type and amount of reinforcement, excellent surface finish can be achieved.

Continued research and development efforts concerning the constituent materials available to pultruders offer the opportunity for the pultrusion industry to continue to expand its markets and improve the overall quality of pultruded composites.

Mississippi Pultrusion WWW Homepage

<http://www.olemiss.edu/depts/compmatl>

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