FINAL REPORT

Identification Number: R-5-38017

Project Title: Low Cost Renewable resin for Pultruded Products

Principal Investigator: K. Chandrashekhara

Project Duration: 07/01/98 – 06/30/01

PROJECT SUMMARY:

Composite materials offer many superior properties that have enabled composite manufacturers to gain significant market share in a variety of industries. Benefits such as high strength to weight ratios and excellent resistance to environmental exposures provide significant advantages over conventional materials. A composite material contains a reinforcement (such as fibers) supported by a binder (resin) material. High cost and lack of ductility are disadvantages of composites that could be overcome by the development of a more flexible, damage tolerant resin system. Our research has focused on using Epoxidized Soybean Oil (ESO), Methyl-Epoxidized Soybean Oil(MESO) and Allyl-Epoxidized Soybean Oil (AESO) as toughening agents to epoxy resin to be used in pultrusion. MESO and AESO were developed by UMR. ESO is produced by several companies and sells for about $.50 per pound. The research to-date includes qualitative screening of resin formulations, determining mechanical properties of neat resins and pultruded reinforced carbon rods.

TASK I – Neat Resin Samples

Neat resin coupons were fabricated using Epon 826/Epicure 9551 epoxy resin system with 10%, 20% and 30% concentrations of ESO, MESO, and AESO. These coupons were tested in tension and three-point flexure as per ASTM standards. The mechanical performance of these resin blends was compared to that of pure Epon 826/Epicure 9551 epoxy resin. Table 1 shows the results of flexural tests. The flexural modulus of a material with a 10% proportion of MESO and AESO materials is higher than that for the pure epoxy system. This behavior indicates that MESO and AESO resins have higher fracture toughness than the Epon 826/Epicure 9551 epoxy system.

TASK II – Pultruded Composite Rods

A prototype pultrusion run with the resins was accomplished. The laboratory scale pultrusion machine is designed and constructed at UMR. Carbon reinforced rods of 0.25 inch diameter were pultruded using a resin formulation made with ESO, MESO and AESO soybean additives. Zoltek Panex 33 carbon fiber was used as the reinforcement. By adding the soyoils to the epoxy, the viscosity of the resin system was reduced showing better flow and consequently, better fiber wet-out. The composite rods produced were tested in tension using a Tinius Olsen Universal tensile test machine and mechanical extensometer with 2 in. gauge length. The results of the tensile testing are shown in Table 2. The average ultimate failure stress of all the soybean oil supplemented rods were higher than pure epoxy resin reinforced rods. This is not unexpected since tensile modulus is mainly a function of stiffness of the fibers, whereas ultimate failure strength may also be influenced by the quality of the resin matrix. The tested soybean additives are believed to yield a twofold benefit. First, the improved fiber wet-out tends to alleviate the fiber/matrix interface bonding weakness. Second, the more flexible resin obtained by adding the soybean materials is believed to inhibit initial matrix crack formation and subsequent propagation.

LIST OF PUBLICATION:

1. K. Chandrashekhara, Virgil J. Flanigan, Nicholas Berring and John Unser, APultrudable Resin from Soybean Oil,@ Proceedings of the 44th International SAMPE Symposium and Exhibition, pp.1857-1865, Long Beach, CA, May 23-27, 1999.
2. Nicholas S. Berring, AManufacturing and Characterization of Composites Using Recycled and Renewable Materials@, M. S. Thesis, University of Missouri-Rolla, January 2000.

Table 1 - Flexure Properties for Neat Resin Coupons

Resin Formulation	Stress at Yield for each sample (MPa) No	Values	Average Peak Stress (MPa)	Flexural Modulus (MPa)	Average Flexural Modulus (MPa)
100% Epon 826	1	109.8	**109.8** Std. Dev. 0.9	2564.2	**2556.6** Std. Dev. 35.0
	2	109.8		2558.6	
	3	109.9		2520.7	
	4	109.0		2529.7	
	5	111.4		2609.7	
90/10 Epon 826 / Witco ESO	1	123.2	**124.5** Std. Dev. 1.7	3070.9	**3070.0** Std. Dev. 37.4
	2	125.1		3088.2	
	3	123.6		3016.5	
	4	127.3		3117.1	
	5	123.2		3057.1	
80/20 Epon 826 / Witco ESO	1	101.7	**102.7** Std. Dev. 1.1	2510.4	**2596.7** Std. Dev. 63.6
	2	104.3		2652.4	
	3	102.4		2621.4	
	4	103.2		2649.7	
	5	101.7		2549.7	
90/10 Epon 826 / MESO	1	114.5	**115.1** Std. Dev. 1.4	2791.7	**2855.5** Std. Dev. 49.1
	2	115.7		2843.4	
	3	112.9		2870.3	
	4	116.2		2926.8	
	5	116.3		2845.5	
80/20 Epon 826 / MESO	1	85.1	**84.9** Std. Dev. 0.4	2360.1	**2319.8** Std. Dev. 29.5
	2	84.5		2321.5	
	3	84.6		2295.3	
	4	85.5		2334.6	
	5	84.7		2287.7	
90/10 Epon 826 / AESO	1	124.2	**124.0** Std. Dev. 1.1	3068.2	**3096.8** Std. Dev. 32.8
	2	125.7		3055.8	
	3	123.9		3113.7	
	4	122.9		3115.7	
	5	123.4		3130.9	

Table 2 - Tensile Properties of Composite Rods

Resin Formulation	Failure Stress (MPa)		Young's Modulus (GPa)	
	Individual	Average	Individual	Average
Epon 826/ Epicure 9551	1095.6	**1197.3** Std Dev 88.5	112.7	**111.3** Std Dev 3.0
	1208.6		114.9	
	1175.6		109.1	
	1309.3		108.5	
90% Epon 826 10% ESO/ Epicure 9551	1432	**1517.3** Std. Dev 54.18	108.6	**109.6** Std Dev 1.5
	1516.8		110.3	
	1529.3		112.0	
	1525.8		109.0	
	1582.3		1082.2	
80% Epon 826 20% ESO/ Epicure 9551	1489.3	**1586.6** Std Dev 98.5	114.9	**110.1** Std Dev 3
	1730.6		107.5	
	1634.1		109.3	
	1508.6		108.0	
	1570.6		111.0	
70% Epon 826 30% ESO/ Epicure 9551	1451.3	**1529.4** Std Dev 86.2	113.8	**113.2** Std Dev 2.1
	1456.2		110.8	
	1629.9		115.2	
	12613.4		111.1	
	1496.2		115.0	
90% Epon 826 10% MESO/ Epicure 9551	1447.9	**1509.1** Std Dev 46.4	112.7	**115.1** Std Dev 4.6
	1621.6		118.3	
	1551.3		108.3	
	1442.4		116.7	
	1482.4		119.5	
80% Epon 826 20% MESO/ Epicure 9551	1525.8	**1494.7** Std Dev 32.6	112.0	**108.7** Std Dev 2.6
	1456.9		107.5	
	1525.8		109.9	
	1499.6		105.0	
	1465.3		109.0	
70% Epon 826 30% MESO/ Epicure 9551	1255.5	**1245.3** Std Dev 57.7	110.7	**110.2** Std Dev 3.4
	1165.2		115.2	
	1324.5		108.4	
	1224.5		106.0	
	1256.9		110.7	
90% Epon 826 10% AESO/ Epicure 9551	1572.0	**1525.3** Std Dev 41.9	114.4	**118.1** Std Dev 12.6
	1569.2		135.1	
	1496.2		127.0	
	1485.8		104.8	
	1503.0		109.2	
80% Epon 826 20% AESO/ Epicure 9551	1522.4	**1456.2** Std Dev 51.2	111.6	**107.3** Std Dev 3.2
	1413.4		109.6	
	1432.0		104.4	
	1499.6		104.8	
	1413.4		106.0	
70% Epon 826 30% AESO/ Epicure 9551	1217.6	**1254.4** Std Dev 36.2	110.8	**107.7** Std Dev 2.8
	1290.0		105.4	
	1255.5		106.9	