



# CENTER FOR INFRASTRUCTURE ENGINEERING STUDIES

Manufacturing and Performance Evaluation of Soy Protein Based  
Plastics and Composites

By

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**UTC  
R134/R148**

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16. Abstract  The objective of the proposed research is to manufacture composite products using soy-based resin system. A novel soy based resin, Epoxidized Allyl Soyate (EAS) has been synthesized and evaluated at the University of Missouri–Rolla. The EAS resin, in general, is more ductile and exhibits higher strains to failure without a significant reduction in modulus as compared to the base Epon Shell resin. The suitability of using EAS resin is being investigated to manufacture environmentally benign composite structures. In Phase I of the project, impact properties of the pultruded soy-based composites were studied. Results show that the EAS resin system imparts higher energy absorbing characteristics and lower impact damage compared to the Epon Shell rein. In Phase II of the project new epoxy foam was synthesized using the soy based resin system developed at UMR. The relation between the composition, density and properties of the foam was analyzed. The cure kinetics and rheology of the soy-based resin system were also studied and analytical models were developed. These models for the cure kinetics and rheology of the soy-based epoxy resin system can be readily applied into numerical modeling of various composite manufacturing processes.					
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**FINAL REPORT**  
**UMR - UNIVERSITY TRANSPORTATION CENTER**  
**ADVANCED MATERIALS AND NON-DESTRUCTIVE TESTING TECHNOLOGIES**

**Sequential #:** R134/148

**Project Title:** Manufacturing and Performance Evaluation of Soy Protein Based Plastics and Composites

**Matching Research Agency:** Missouri Soybean Merchandising Council

**Principal Investigator:** K. Chandrashekhara, Professor, Department of Mechanical and Aerospace Engineering

**Project Duration:** 7/1/04-6/30/06 (2 years)

**Project Summary:**

The objective of the proposed research is to manufacture composite products using soy-based resin system. A novel soy based resin, Epoxidized Allyl Soyate (EAS) has been synthesized and evaluated at the University of Missouri–Rolla. The EAS resin, in general, is more ductile and exhibits higher strains to failure without a significant reduction in modulus as compared to the base Epon Shell resin. The suitability of using Epoxidized Allyl Soyate (EAS) resin is being investigated to manufacture environmentally benign composite structures. In Phase I of the project, impact properties of the pultruded soy-based composites were studied. Results show that the EAS resin system imparts higher energy absorbing characteristics and lower impact damage compared to the Epon Shell resin. In Phase II of the project new epoxy foam was synthesized using the soy based resin system developed at UMR. The relation between the composition, density and properties of the foam was analyzed. The cure kinetics and rheology of the soy-based resin system were also studied and analytical models were developed. These models for the cure kinetics and rheology of the soy-based epoxy resin system can be readily applied into numerical modeling of various composite manufacturing processes.

**PUBLICATIONS:**

1. S. Sundararaman, A. Shabeer, A. Garg, K. Chandrashekhara, V. Flanigan and S. Kapila, “Impact Characterization of Pultruded Soy-based Composites,” Proceedings of the SAMPE Conference, Long Beach, CA, pp. 1-10, May 1-5, 2005.
2. G. Liang and K. Chandrashekhara, “Cure Kinetics and Rheology Characterization of Soy-based Epoxy Resin System,” Journal of Applied Polymer Science (In Press).
3. R. Yadav, A. Shabeer, S. Sundararaman, K. Chandrashekhara, V. Flanigan and S. Kapila, “Development and Characterization of Soy-based Epoxy Foams,” Proceedings of the SAMPE Conference, Long Beach, CA, pp. 1-10, May 1- 4, 2006.

**Summary of Results:**

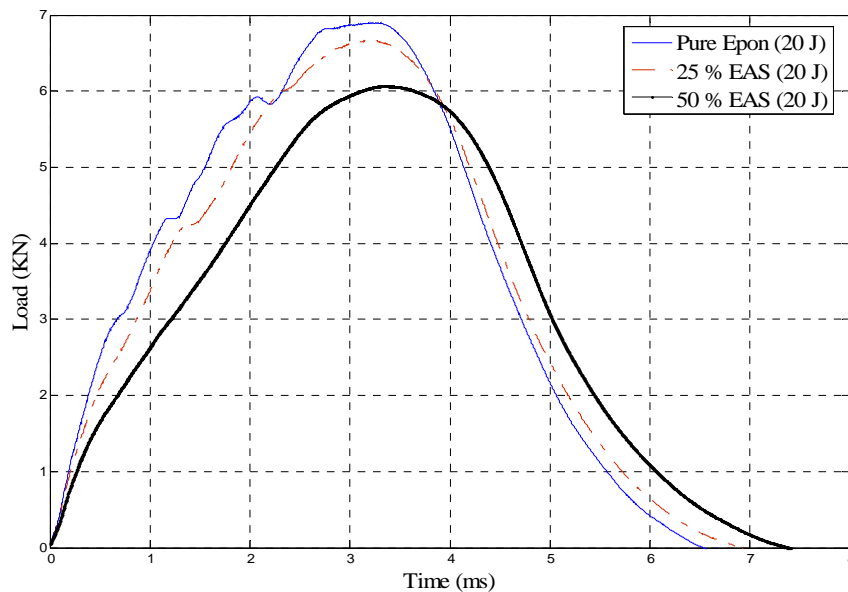
PHASE I:

Pultruded composite samples with improved soy resin formulations have been manufactured. Soy-based resin is ideal for pultrusion process since it increases the line speed and reduces the pull force. Mechanical tests of pultruded coupons indicate that the resin system can be used to manufacture high performance pultruded composites. Glass fiber reinforced composite panels were manufactured using three different resin systems, pure Epon, 25% EAS and 50% EAS. Low velocity impact tests were performed on these specimens at different impact energy levels. The effect of soy resin content on the contact force is shown in Figure 1. The contact force for pure Epon composite specimens is the highest and is followed by 25 % EAS and 50% EAS resin systems. As the concentration of soy resin increases, the contact force decreases. A lower contact force results in smaller values of

local stresses in the specimen resulting in lesser damage. Also, the specimens with EAS had smaller damages as compared to pure Epon specimens as shown in Figure 2. The details of this study can be seen in [1].

### PHASE II:

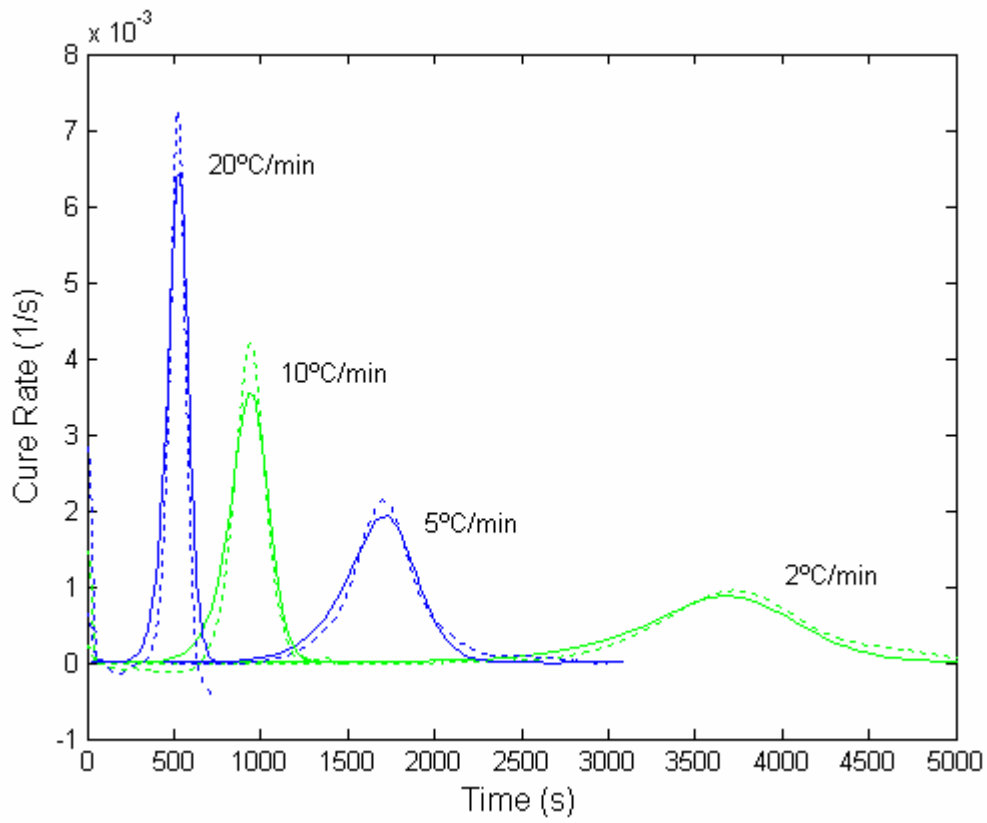
The cure kinetics and rheology of the soy-based resin system were also studied and analytical models were developed. Figure 3 shows the comparison of the experimental data with the cure model developed. The details of this study can be seen in [2]. Epoxy foams have been developed using soy-based resin system synthesized at University of Missouri – Rolla (Figure 4). The performance of foams was evaluated by testing for compression in both parallel and perpendicular to rise direction. The tests were carried out at room temperature and at the elevated temperature. The compression properties showed a decreasing trend for increasing amounts of soy resin. The density (Figure 5) and the thermal properties of the epoxy foams were also evaluated. The relation between the composition, density and properties of the foam was analyzed. Soy-based epoxy foams are potential low cost and environmentally benign materials for structural applications [3].



**Figure 1.** Contact force for various resin formulations



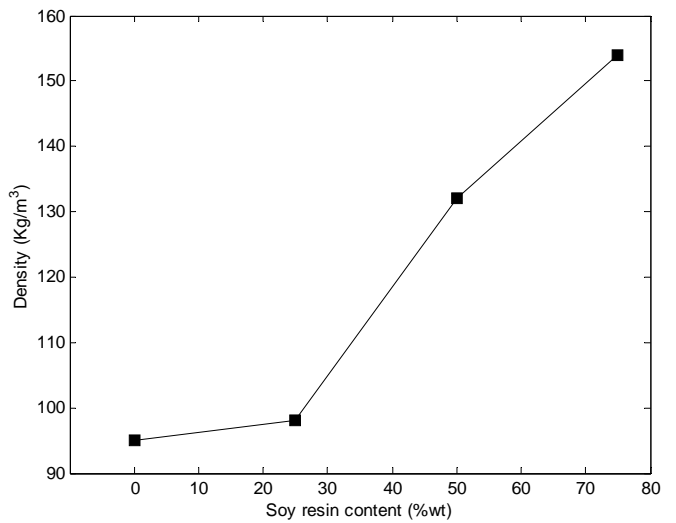
**Figure 2.** Front surface of composite samples impacted at 5 Joules



**Figure 3.** Comparison of Experimental Data (--) with the Kinetic Model Data (-) at Different Heating Rates



**Figure 4** Soy foam developed at UMR



**Figure 5** Variation of density with soy resin concentration