Center for Transportation Infrastructure and Safety

Pultruded Composites Using Soy-based Polyurethane Resine

by

K. Chandrashekhara

A National University Transportation Center
at Missouri University of Science & Technology

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16. Abstract

Fiber Reinforced Polymer (FRP) composites offer inherent advantages over traditional materials with regard to high strength-to-weight ratio, design flexibility, corrosion resistance, low maintenance, and extended service life. FRP materials can be used to replace traditional building materials like steel and wood. The application of composite materials will reduce cost and improve durability. One of the major cost drivers for composites is raw materials. Use of soybean-derived materials offers low cost raw materials. Development and performance evaluation of pultruded soy-based polyurethane composite panels is the focus of the proposed research. Soy-based polyurethane (PU) resin offers several benefits such as improved properties, faster production, and reduced VOC emissions. Missouri University of Science and Technology (MST) is collaborating with United Soybean Board (USB) to develop soy-based PU pultruded products for affordable housing and other commercial applications. Solid and core-filled pultruded parts will be manufactured at MST and the performance of these products will be evaluated. Based on the test results, the resin chemistry will be modified to achieve improved structural performance and also to incorporate more soy content in the formulation without property degradation.

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MISSOURI S&T – NATIONAL UNIVERSITY TRANSPORTATION CENTER
ADVANCED MATERIALS, TRANSITION-STATE FUEL VEHICLE INFRASTRUCTURE AND NON-DESTRUCTIVE TESTING TECHNOLOGIES

Sequential #: R211 - 00019232

Project Title: Pultruded Composites using Soy-based Polyurethane Resin

Matching Research Agency: United Soybean Board

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

Project Duration: 10/1/07-6/30/08

Project Summary:

Fiber Reinforced Polymer (FRP) composites offer inherent advantages over traditional materials with regard to high strength-to-weight ratio, design flexibility, corrosion resistance, low maintenance, and extended service life. FRP materials can be used to replace traditional building materials like steel and wood. The application of composite materials will reduce cost and improve durability. One of the major cost drivers for composites is raw materials. Use of soybean-derived raw materials offers low cost alternatives. Development and performance evaluation of pultruded soy-based composite panels is the focus of the proposed research. Soy-based polyurethane (PU) and soy-based polyester (PE) resin system available from different sources have been evaluated to manufacture pultruded composite parts.

Publication:

R. R. Vuppalapati, K. Chandrashekhara and W. E. Showalter, Impact Characterization of Core-filled Pultruded Biocomposite Panels, Proceedings of the SAMPE Conference, pp. 1-10, Memphis, TN, September 8-11, 2008 (To appear).

Summary of Results:

Pultrusion is considered to be the fastest and most economical of composite manufacturing processes. In the pultrusion process, many uniform cross-section profiles can be manufactured continuously as long as raw materials are supplied. Fiber reinforcement can take form of any one or combination of several types such as rovings, mats, fabrics, and cloths. Glass fiber reinforced composite panels were manufactured using Durapul 6000 LABSTAR pultrusion machine at Missouri University of Science and Technology (Formerly, University of Missouri-Rolla). The schematic of the pultrusion process is shown in Figure 1.

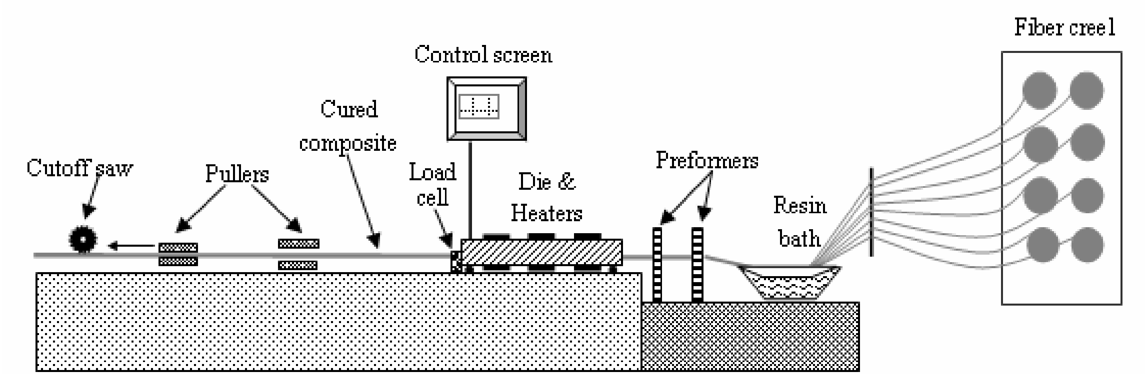

Figure 1. Schematic of Pultrusion Process

The pultrusion machine mainly consists of the following elements: (1) Roving racks and cloth creels which provide continuous fiber reinforcement; (2) Wet resin bath saturates fibers with polymeric resin; (3) A series of preformer fixtures form the impregnated fiber package to shape the wetted fibers before entering die and remove excess resin; (4) The heated die is made of chrome-plated steel and consists of multiple pieces depending on the cross-section geometry of the product. Six electric resistance heater cartridges are in direct contact with the upper surface and lower surface of die to form three heating zones to assist cure; (5) Puller system and cut-off saw; (6) Computer control interface. The die cavity used for manufacturing the rectangular shaped composites was 2 in. wide, 0.125 in. thick and 36 in. long. The six cartridge heaters supply a maximum 750 watt of power to heat the die. The three heating zones are independently controlled by the computer interface through thermostats embedded inside the die to achieve a variety of die temperature profiles.

During pultrusion, the compacted resin/fiber bundle is continuously pulled through the heated die. The temperatures are set in three zones based on the type of the resin system used. The heat is transferred from the high temperature die wall to the fiber/resin bundle where the resin is cured. The cured sample exits from the die and is pulled by the pullers to the cut-off saw where the samples are cut to desired length. In the present work, two types of soy-based resin systems were studied.

Manufacturing of Polyester and Soy-Polyester Composites using Pultrusion

Two types of polyester (PE) resin systems were considered in the present work. The temperature of the die was maintained at 250-300°F. Pultruded parts were manufactured at a line speed of approximately 1-2 ft/min. Tensile, flexure and impact tests were performed on the pultruded PE parts to evaluate their mechanical properties.

Tensile test: Tension tests were carried out on pultruded solid composite samples. Tensile tests were performed on an Instron testing machine in accordance with ASTM D3039. The tests were conducted at a cross head speed of 1.3 mm/min (0.05 in/min). Table 1 lists the tensile modulus, tensile strength and the failure strain of the pultruded composite. Tensile stress-strain curves for base PE and soy-PE pultruded composites are shown in Figure 2. The base PE pultruded panels had a tensile modulus of 47.9 GPa and strength of 734 MPa while the soy-PE pultruded panels had a tensile modulus of 41.3 GPa and tensile strength of 654 MPa.

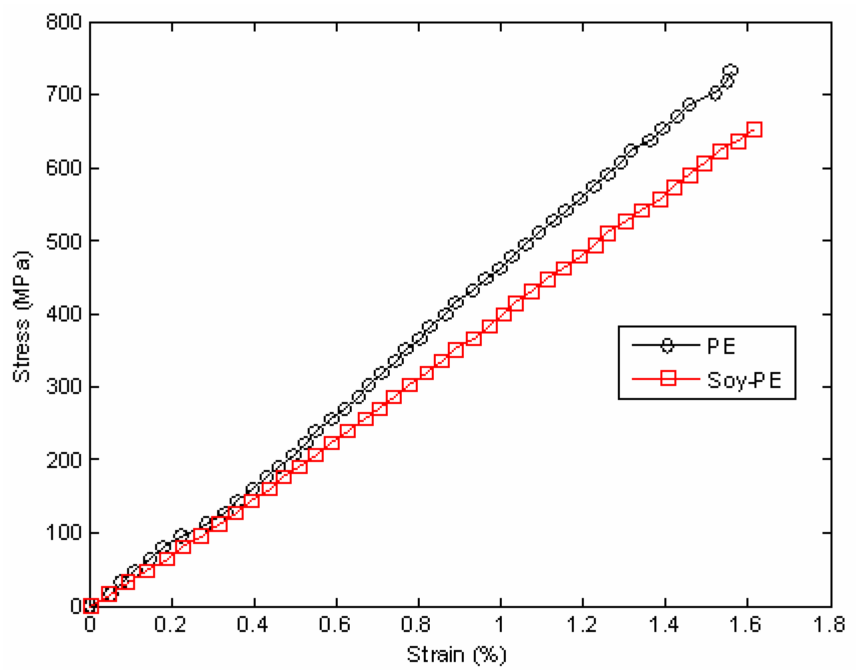

Figure 2. Tensile Curve of PE and Soy-PE Composites

Table 1. Tensile Properties of Solid PE and Soy-PE Composites

	Tensile Modulus (GPa)	Tensile Strength (MPa)	Strain to Failure (%)
Base PE composite	47.9 ± 2.1	734 ± 19	1.56 ± 0.11
Soy-PE composite	41.3 ± 1.6	654 ± 24	1.61 ± 0.14

Flexure test: Solid pultruded panels were tested for flexural strength and flexural modulus on an Instron testing machine according to ASTM D790. Five specimens of 152 mm (6 in) x 13.2 mm (0.52) in x 1.01 mm (0.04 in) size with a span of 50.8 mm (2 in) were used for testing. Tests were carried out at a crosshead speed of 2.5 mm/min (0.1 in/min). The base PE pultruded panels had a flexure modulus of 42.7 GPa and flexural strength of 853.4 MPa while the soy-PE pultruded panels had a flexure modulus of 38.9 GPa and flexure strength of 603.5 MPa. Typical base PE pultruded composite and soy-PE pultruded composite flexural stress-strain curves are shown in Figure 3. Table 2 lists the flexure properties of the pultruded composite.

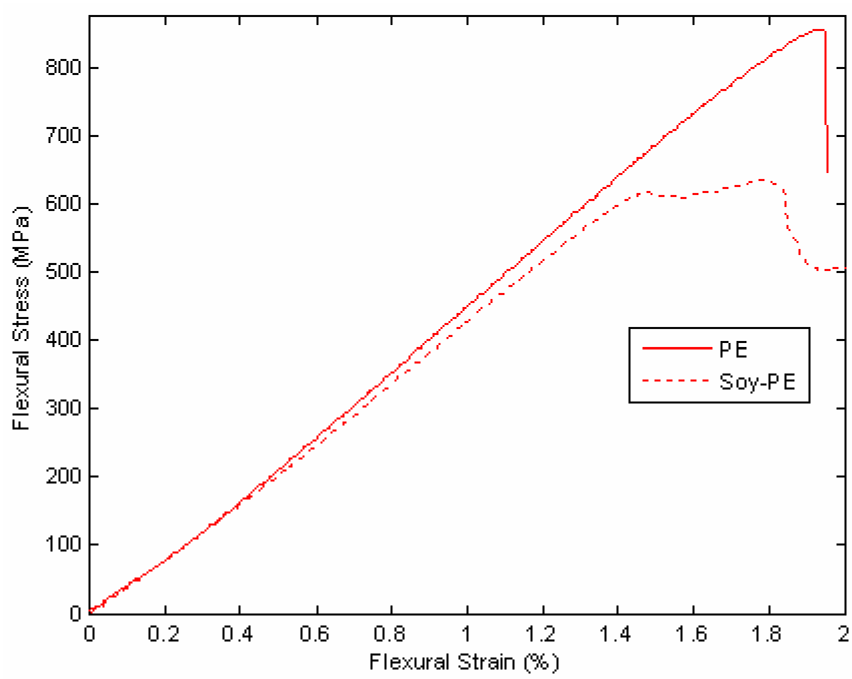

Figure 3. Typical Flexure Curve of PE Composites

Table 2. Flexural properties of solid PE and Soy-PE composites

	Flexural Modulus (GPa)	Flexural Strength (MPa)	Flexural Strain to Failure (%)
Base PE composite	42.7 ± 1.5	853.4 ± 18.7	1.9 ± 0.12
Soy-PE composite	38.9 ± 1.4	603.5 ± 19.9	1.66 ± 0.15

Impact test: Low velocity impact tests were conducted on core-filled pultruded composite panels. A Dynatup Instron Model 9250 Impact Testing Machine with impulse control and data system was used to carry out the impact tests. The measurement of contact force, transient deflection and impact energy can be used to assess the extent of damage in composite structures. The width of the impact test specimens was 2 in and the specimens were supported over a 1.75 in x 1.75 in opening. The impactor had a mass of 6.48 kg and a diameter of 0.5 in. Impact tests were conducted at energy levels of 15 J, 20J and 25J on both base PE and soy-based PE solid panels. Three specimens each were tested. The specimen was first clamped in the fixture. The impactor was then dropped from the desired height onto the clamped specimen. As the impactor made contact with the specimen, the data acquisition system was triggered to start acquiring data. Figure 4 shows the variation of energy with time while Figure 5 shows the variation of the contact force with time. Figures 4 and 5 indicate that the soy-based PE samples have similar impact properties when compared to that of the base PE samples.

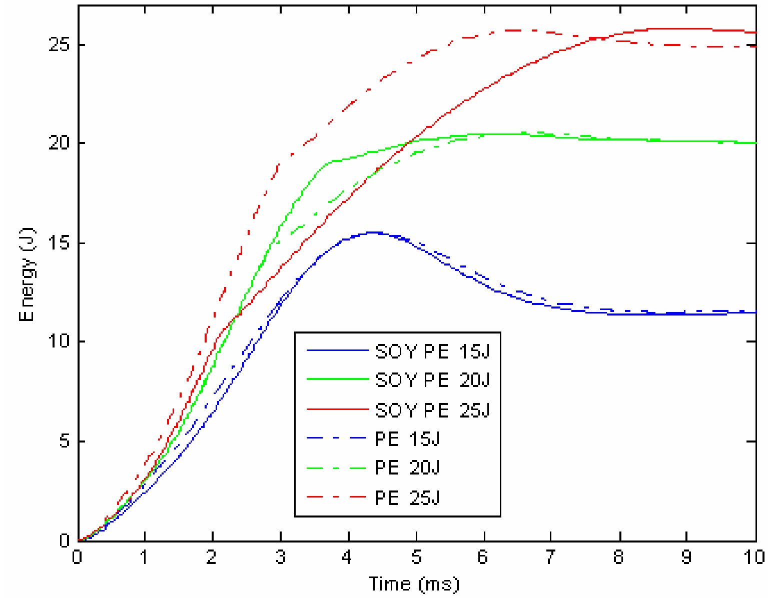

Figure 4. Impact Energy vs. Time

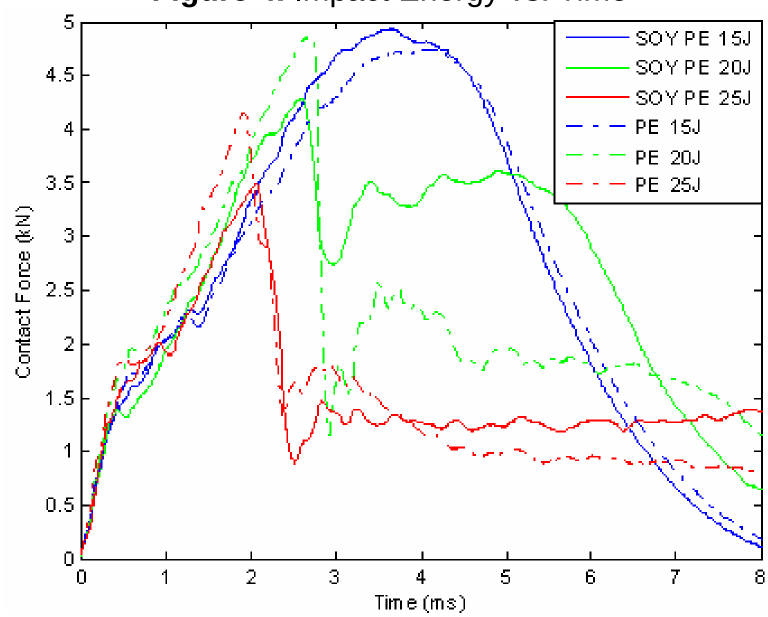

Figure 5. Contact Force vs. Time

Manufacturing of Polyurethane and Soy-Polyurethane Composites using Pultrusion

Pultrusion setup used during the PE pultrusion was modified for the manufacturing of polyurethane (PU) pultrusion. Pultrusion of PU resin system requires an injection box and a resin metering unit. Pultruded composite panels have been manufactured using the PU resin system. Figure 6 shows the manufactured composite panel.

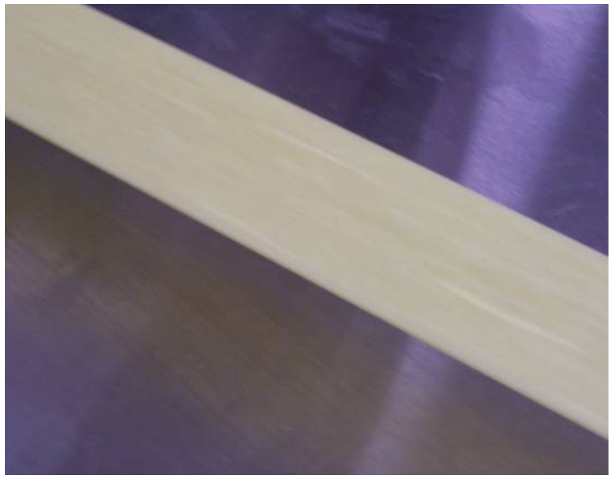

Figure 6. Pultruded Soy-polyurethane Sample

Tensile, flexure and impact tests were conducted on the pultruded polyurethane panels. The results from the tests are summarized below.

Tensile test: Table 3 lists the tensile modulus, tensile strength and the failure strain of the pultruded composite. Tensile stress-strain curves for base PU and soy-PU pultruded composites are shown in Figure 7. The base PU pultruded panels had a tensile modulus of 55.3 GPa and strength of 755 MPa while the soy-PU pultruded panels had a tensile modulus of 57.2 GPa and tensile strength of 757 MPa. From the results one can observe that there is minimal difference in the tensile properties of the PU resin systems.

Table 3. Tensile Results of PU Composites

	Tensile Modulus (GPa)	Tensile Strength (MPa)	Strain to Failure (%)
Base PU composite	55.3 ± 1.8	755 ± 14	1.36 ± 0.18
Soy PU composite	57.2 ± 1.2	757 ± 13	1.31 ± 0.21

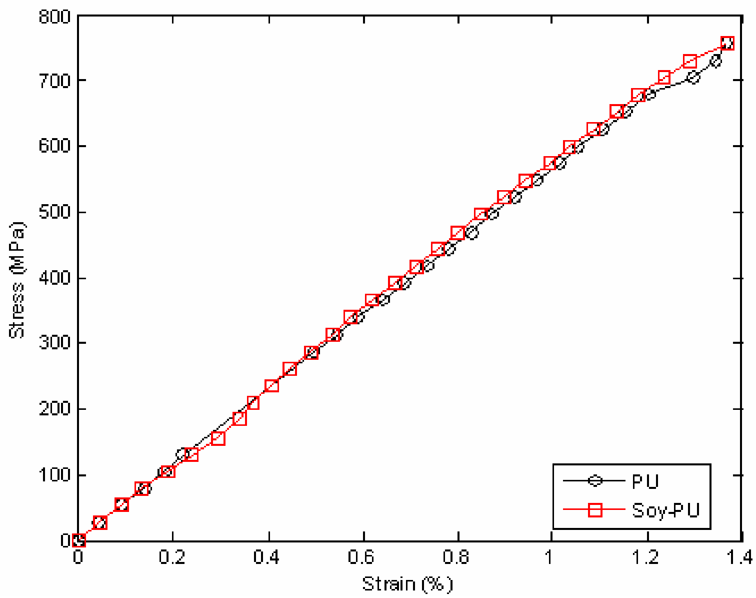

Figure 7. Typical Tensile Curve of PU Composites

Flexure Test:

Five samples of dimensions 0.5 in x 6 in were used for testing. The flexural modulus and flexural strength are tabulated in Table 4. The results indicate that the flexural modulus and flexural strength of soy-PU are similar to that the base PU. Figure 8 shows a typical stress-strain curve for PU and Soy-PU pultruded composites.

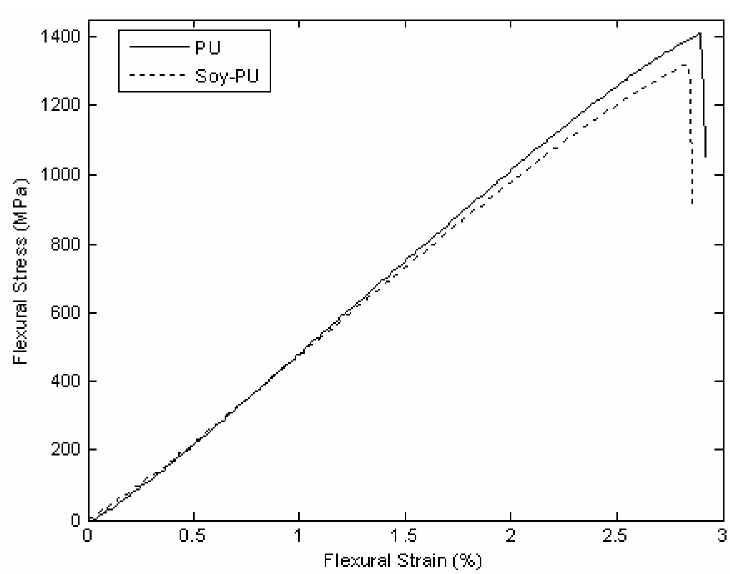

Figure 8. Flexure Curve of PU Composites

Table 4. Pultruded Flexure Results of PU Composite Panels

	Modulus (GPa)	Flexure Strength (MPa)	Strain to Failure (%)
Pultruded Base PU composite	**46.73±4.13**	**1271.54±106.83**	**2.78±0.21**
Pultruded soy-PU composite	**44.66±1.42**	**1284.25±46.26**	**2.96±0.07**

Impact Test:

A Dynatup Instron Model 9250 Impact Testing Machine with impulse control and data system was used to carry out the low velocity impact tests. As the pultruded PU samples were only 2 in. wide, a fixture with an opening of 1.75 in. x 1.75 in. was used for the impact tests. The impactor had a mass of 6.48 Kg and a diameter of 0.5 in. Three different energy levels of 15J, 20J and 25J were considered. Five specimens were tested for the PU and the soy-based PU pultruded samples at each energy level.

Figure 9 plots the impact energy as a function of time. The curves can be divided into three phases. The first phase of the curve (energy increase with time) indicates the transfer of energy from the impactor to the specimen while the second part of the curve (energy decrease with time) shows the transfer of energy from the specimen back to impactor. The final phase (flat region) shows the energy absorbed by the specimen. From Figure 9 it is clear that the energy absorbed by the pultruded PU composites and soy-based PU composites are comparable.

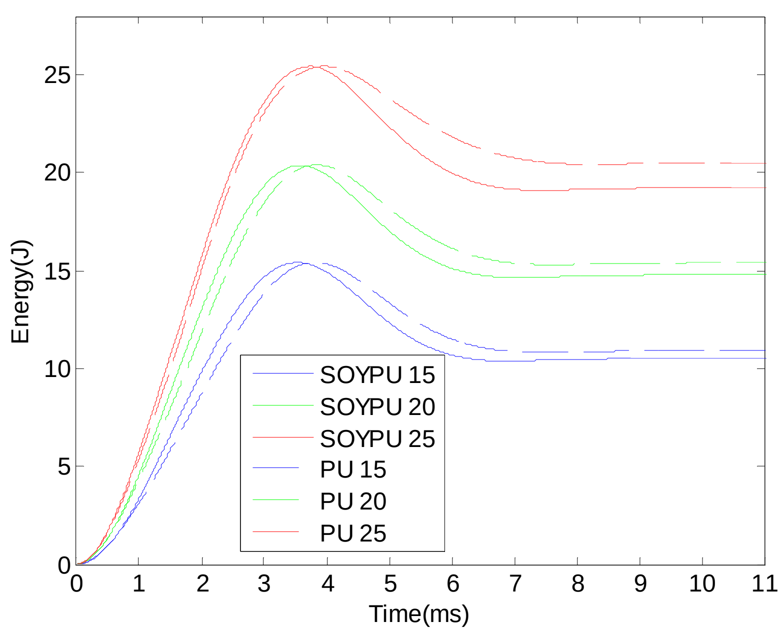

Figure 9. Impact Energy vs. Time

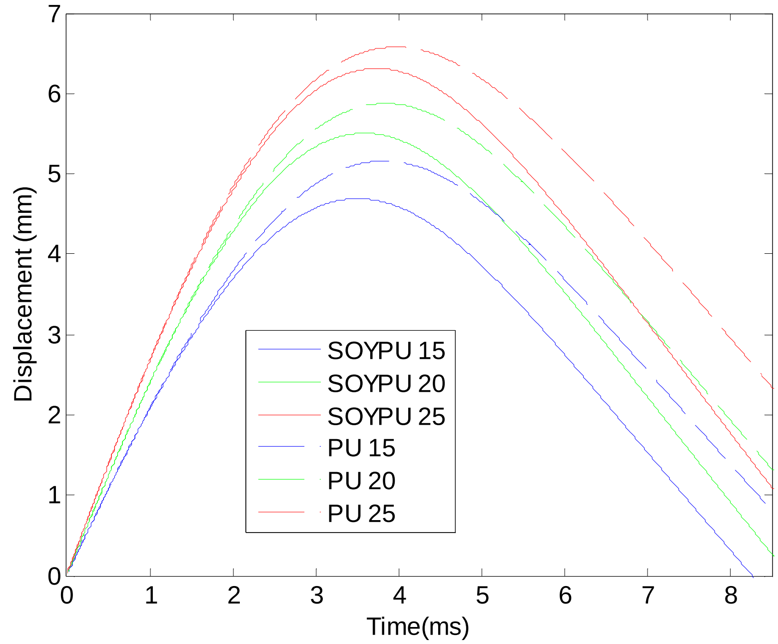

Figure 10. Impactor Displacement as a Function of Time

Figure10 shows the impactor displacement of the pultruded sample as a function to time. PU pultruded samples showed higher displacement than that of the soy PU samples, indicating that base soy-based PU composites have higher stiffness than the PU composites.

We have also manufactured core-filled soy-based panels using polyester resin system. Figure 11 shows the core-filled panel. Details on the core-filled pultrusion are given in the reference.

Figure 11. Core-filled Composite Manufactured at Missouri S&T