Viscoelastic Behavior of Foamed Polystyrene/Paper Composites

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Introduction

This paper outlines a simple lab experiment for high school students or freshman engineering students designed to demonstrate the principle behind why sandwich composites are so stiff as well as light-weight. A sandwich composite consists of a very lightweight core (such as a foamed polymer or honeycomb structure) with sheets of another material (such as paper, plastic, fiberglass, or aluminum) on the top and bottom surfaces. Applications for sandwich composites requiring both high-stiffness and lightweight include aircraft panels, boat hulls, jet skis, snow skis, partitions, and garage doors. In this experiment, the students measure the increase in stiffness when the top and bottom skins of paper are added to a Styrofoam beam to form the sandwich composite. Also this experiment includes a creep test in which the students measure and plot the deflection of the Styrofoam beam versus time to illustrate the viscoelastic behavior of Styrofoam.

Materials and Equipment Required

1. A sheet of Styrofoam (foamed polystyrene) approximately 122 cm (4 ft) long, 35.5 cm (14 in) wide, and 1.83 cm (0.72 in) thick.
2. A metal frame with a clamp to hold one end of the Styrofoam beam.
3. Six metal washers, about 3.8 cm (1.5 in) diameter.
4. One jumbo paperclip.
5. One large paper grocery bag.
6. Scissors, cutting knife, and paper glue.
7. A ruler or meter stick.
8. A weighing scale or balance
9. A computer with MS Excel

Procedure

For each group of students performing this experiment, at least four rectangular bars approximately 2.5 cm (1 in) wide and 35.5 cm (14 in) long were cut from the Styrofoam sheet. Moreover, at least four paper strips, also approximately 2.5 cm (1 in) wide and 35.5 cm (14 in) long were cut from the grocery bag. The students then constructed the following four Styrofoam beam configurations:

A. Styrofoam bar with no paper.
B. Styrofoam bar with paper strip glued to the top surface.
C. Styrofoam bar with paper strip glued to the bottom surface.
D. Styrofoam bar with paper strips glued to the top and bottom surfaces.

The glue was allowed to dry thoroughly before testing the beams. The six metal washers were each weighed and their weights written on their sides. Starting with beam A, one end of the bar was clamped as a cantilever beam in the metal frame as shown in the photo in Figure 1. A jumbo paperclip was bent into a shape such that it penetrated the free end of the beam and looped to allow the hanging of six washers. The other end of the paperclip was bent horizontally to act as a pointer to read the vertical height of the beam end above the countertop using a ruler or meter stick. Before adding any washers onto the paperclip, the beam dimensions of b, d, L (as defined below), and the initial height above the countertop were measured and recorded. Then the washers were added one at a time with height measurements taken after 10 seconds of adding each washer. This procedure continued until either the beam broke or all six washers had been added. All four beam configurations were tested in this same manner. On the data sheet seen in Table 1, the free-end deflection δ was found by subtracting the loaded height from the initial unloaded height. The cumulative weight on the beam was found by adding the weights of all the washers that were currently attached. Using the weight and deflection data shown in Table 1, four weight-versus-deflection curves, one for each beam configuration, were constructed as shown in Figure 2.

Finally a creep or viscoelastic test was conducted on the beam A while a constant load of two washers was maintained for 20 minutes, whereupon the load was removed. Deflection measurements were taken at various time intervals (generally every 5 minutes). After the load was removed at the 20-minute time period, deflection measurements were acquired for an addition 10 minutes to test for recovery of the deflection. Data from this creep test is shown in Table 2 and plotted in Figure 3.

Analysis of the Curves and Conclusions

By drawing a straight line through the first several data points on each weight-versus-deflection curve seen in Figure 2, the slope W/δ value for each beam was found graphically. Then by substituting this W/δ value into the following equation,[1] the elastic modulus E of each beam was calculated:

$$E = \frac{4L^3 W}{bd^3 \delta}$$

where L = unsupported beam length (from clamp to free end)
W = weight of attached washers
b = beam width
d = beam thickness
δ = free end deflection = unloaded height – loaded height

For beam A: W/δ = 8.7 g/cm and E = 55 kg/cm^2
For beam B: W/δ = 24 g/cm and E = 152 kg/cm^2
For beam C: W/δ = 28 g/cm and E = 174 kg/cm^2
For beam D: W/δ =105 g/cm and E = 651 kg/cm^2

Note that the stiffness of beam D is 12 times that of beam A. This is a remarkable increase in stiffness due only to the presence of the paper skins.

The creep curve as seen in Figure 3 demonstrates the viscoelastic nature of the polystyrene. The instantaneous deflection of 4 cm upon the applying of the load and unloading at 20 minutes is the result of the elastic strain. The slowly increasing deflection during the first 20 minutes is due to viscous flow of the polystyrene. Part of this deflection is recovered over time after the load is removed as seen on the curve between 20 and 30 minutes. This type of viscoelastic behavior must be considered when a plastic or elastomeric part is to support a constant load over a long period of time.

Bibliography

1. W. Callister, Materials Science & Engineering: An Introduction, John Wiley & Sons (2000).

Biography

ROBERT A. MCCOY is a professor of Mechanical Engineering at Youngstown State University, Youngstown, Ohio. He has bachelor's and master's degrees from Ohio State University and a Doctor of Engineering degree from University of California at Berkeley. At YSU, he teaches freshmen engineering, mechanical engineering, and materials engineering courses. He is also a failure analysis consultant and a member of ASM and ASEE.

Table 1. Cantilever Beam Data

Beam A L = 26.8 cm

W (g)	Ht (cm)	δ (cm)
0.0	30.4	0.0
17.09	28.5	1.9
34.59	26.4	4.0
51.80	23.8	6.6
69.42	20.3	10.1
86.96	excessive deflection	

Beam B L = 26.9 cm

0.0	32.6	0.0
17.09	32.0	0.6
34.59	31.2	1.4
51.80	30.1	2.5
69.42	28.9	3.7
86.96	26.8	5.8
104.78	23.5	9.1

Beam C L = 26.7 cm

0.0	28.4	0.0
17.09	27.7	0.7
34.59	27.1	1.3
51.80	26.6	1.8
69.42	26.0	2.4
86.96	25.3	3.1
104.78	24.7	3.7

Beam D L = 26.7 cm

0.0	30.4	0.0
17.09	30.3	0.1
34.59	30.1	0.3
51.80	30.0	0.4
69.42	29.8	0.6
86.96	29.6	0.8
104.78	29.4	1.0

Table 2. Creep Data for Beam A
Loaded with 34.59 g

Time (min)		Ht (cm)	δ (cm)
0	Unloaded	29.8	0
0.1	Loaded	25.8	4.0
1	Loaded	25.7	4.1
3	Loaded	25.6	4.2
5	Loaded	25.55	4.25
10	Loaded	25.45	4.35
15	Loaded	25.4	4.4
20	Loaded	25.35	4.45
20.1	Unloaded	29.4	0.4
22	Unloaded	29.5	0.3
25	Unloaded	29.55	0.25
30	Unloaded	29.6	0.2

Figure 1. Cantilever Beam Fixture

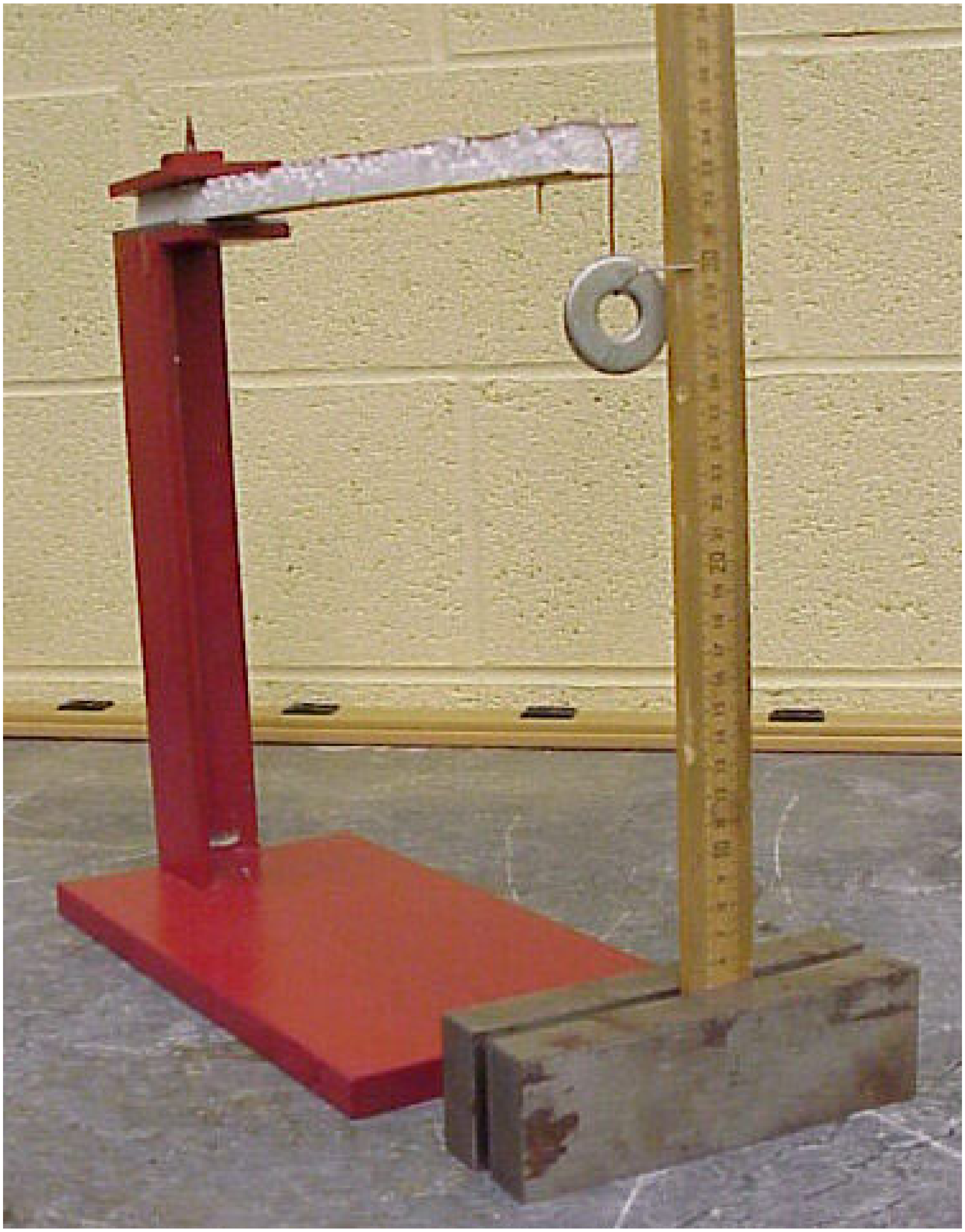

Figure 2. Weight vs. Deflection Curves

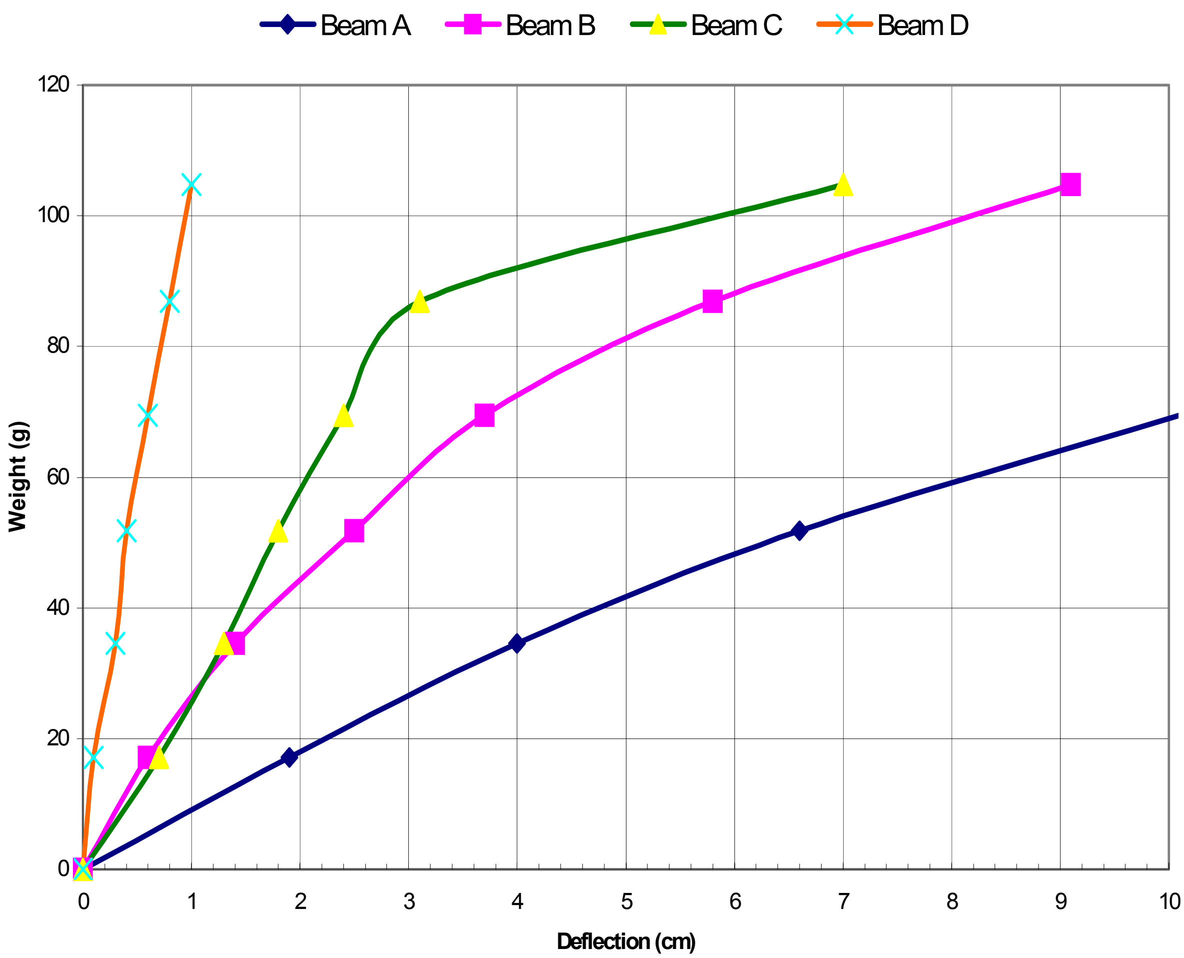

Figure 3. Creep Curve for Beam A

Loaded with 34.59 g at t = 0 and unloaded at t = 20 min