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Core Material for Large Sandwich Structures Based on Blow Molding

by

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Abstract

A core material concept based on blow molded segments is being developed to facilitate the use of very thick sandwich panels, 8 to 24 inches (0.2 to 0.6m) thick, and thicker. The basic concept uses an array of hollow rectangular segments arranged in a sheet, to form the core, with sandwich face skins on top and bottom in the usual way. Once the blow molded core (BMC) segments and skins are bonded together, using resin infusion (or other molding techniques) the sides of the segments form webs which act as though they were continuous; like a giant rectangular honeycomb. The purpose of this study is an initial investigation into the process-ability and shear strength properties of panels made using this approach, and to compare measured properties to model predictions. Panel thicknesses of 4 to 18 inches (0.1-0.46 m) have been demonstrated, and results are reported for 8 inch (0.2m) thick panels in two configurations. The results look promising for making low cost thick sandwich structures.

Introduction

Core materials are an important component in many composite applications from skis, boats, and snow boards, to aerospace structures and highway bridges; just to name a few. As acceptance of sandwich construction has grown, so has the interest in making larger and larger structures. Structures such as highway bridges, ship fenders, helicopter landing platforms and bridge decking are considered as viable candidates for sandwich construction. One difficulty with traditional core materials is that they were developed for relatively thin sandwich structures, from a fraction of an inch up to a few inches thick on the very high end is typical.

To get around this thickness limitation, a variety of options have been tried, and some are in production currently. One possibility is to pultrude deep box sections, where the webs of the box function like the core, separating the top and bottom laminates and providing shear capability to the cross section. This is a good approach for some applications, but uses webs in only one direction, and consequently has the majority of its shear capability in one direction. Some configurations have been tried to help this situation, for example, angling the webs in box section or filling the open space with foam in an attempt to get shear capability transverse to the webs. This does help but it is not as effective as having webs in two mutually perpendicular directions at the same time. Some boat builders make this type of structure when they separate the lower floor in the boat from the hull with an "egg -crate" structure comprised of intersecting longitudinal and transverse framing. The inner floor and hull are attached to the "egg crate" providing a strong structure with shear capability in two directions. Most boat builders will agree that this type of structure is very strong but complicated to make. The question is how to build such a structure efficiently.

One possibility is to use an array of hollow segments as the core, Fig. 1, with face skins on the top and bottom. The segments are then bonded together with resin infusion (or other molding processes), and the sides of the segments act as continuous webs in two directions at the same time. Fig. 2 shows different size segments as well as a molded panel. The small segment is 4"x4"x8" (0.1x0.1x0.2m), and the larger segment is 8"x8"x16" (0.2x0.2x0.4m).

Blow Molding Segments

The blow molded core (BMC) segments are made using a process known as extrusion blow molding. A thermoplastic material is melted and pumped with an extruder through an annular orifice, producing a vertical tube of molten plastic. This tube is quickly clamped between the halves of a two part mold, pinching off the top and bottom, thus sealing the tube. A hollow pin is then inserted, usually through the top of the mold, and through the molten plastic. Air is then forced into the molten tube, expanding it to quickly fill the mold. This all happens very quickly, in a matter of seconds, with typical cycle times in the 15-60 second range depending the part. Thermoplastic materials suitable for extrusion blow molding include high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP), polyvinyl chloride (PVC), polycarbonate (PC), polyethylene terephthalate (PET), and a variety of others.

BMC segments used for testing in the present work are made with HDPE. They are 4"x4"x8" (0.1x0.1x0.2m) in size, and weigh about ¼ pound each (114 grams); see the small segment in Fig. 2. The segments are molded with grooves on the surface to promote resin distribution, and improved buckling resistance.

Structural Configurations

The core segments can be used alone or in combination with fiber reinforcement (e.g. fiber glass fabrics or mats) in a variety of configurations depending on the requirements of the application. Three possible configurations are shown in Fig. 3, they are: 1) segments used alone, 2) segments with fiberglass layers inserted in-between in one direction, and 3) segments wrapped on four sides with fiberglass. Lightly loaded structures may use the segments alone, where the segment material forms the webs and provides the required strength once bonded together. If additional strength (or stiffness) is required in one direction, fiber reinforcement can be inserted between the segments and greatly improve the structural properties in that direction. Wrapping the segments on four sides will provide additional reinforcement in two mutually perpendicular directions. Fig. 2 shows a small segment wrapped with a 72 oz./sq.yd. (2450 gsm) stitch-bonded fabric.

Test Sample Fabrication

Samples for testing were fabricated with two core configurations, one with segments alone (Core #1) as in Fig. 3-1, and one with glass reinforced webs (Core #2) as in Fig. 3-2. Both samples used 4"x4"x8" (0.1x0.1x0.2m) segments made from HDPE, with the 8" direction oriented through the thickness. Fig. 4 shows the infusion mold with segments being loaded inside. Fig. 5 shows the loaded mold, with 2 layers of continuous strand mat (CSM) being added to the top before covering and vacuum infusing with polyester resin. When infused, as shown in Fig. 6, the samples were 20 inches (0.51m) long, 8 inches (0.2m) thick, and 12 inches (0.3m) wide (3 segments wide by 5 segments long). The edges were then cut off of each so the resulting samples were 8" (0.2m) wide, Fig. 7, with effectively 2 webs each. Core #2 added one layer of 1.5 oz./sq.ft. (460 gsm) CSM inserted between segments running in the long direction, as in Fig. 3-2. The segments were sealed to prevent resin from getting inside, and the surface was treated to promote adhesion to polyester resin. Face skins were two layers of 1.5 oz./sq.yd. (460 gsm) CSM each.

Testing

Testing used a 120 kip (534 kN), Baldwin Tate-Emery universal testing machine in compression mode. Steel supports were placed under the panel ends, reducing the test span to 12" (0.3m), and a 4" (0.1m) wide steel plate was placed on top and centered as in Fig. 8. Since the sample is short and thick, this 3 point beam test is effectively a core shear test, very close to ASTM-C393. The load frame was run in stroke control at 0.5 inches per minute (12.7 mm/min), and failure was taken to be when the load drops to 20% below its maximum value. In the case of Core #1, the core webs buckled but did not fail catastrophically at about 5,768 pounds (25.7kN) as shown in Fig. 9. As the webs buckled, the load dropped below 80% of the maximum, the test was stopped and the sample unloaded. Surprisingly, the webs un-buckled and the sample returned to nearly its original shape with little damage. The sample shown in Fig. 8, is actually the sample after it was tested and deformed as in Fig. 9. According to ASTM C393 (Ref. 1) test parameters, the average shear strength of Core #1 based on this test was 45 psi (0.31MPa). Fig. 10 shows the Load-Deflection curves for both test samples.

Core #2 was tested in a similar way to an ultimate load of 15,488 pounds (69.0kN). The webs cracked in a few places, but the panel retained a significant portion of its integrity. The average shear strength of Core #2 based on ASTM C393 was 121 psi (0.83MPa) in the span-wise direction. Shear strength in the transverse direction is expected to be similar to that of Core #1.

Estimating Core #1 Shear Strength

Typical tensile yield strength for HDPE is 4000 psi (27.6MPa, Ref. 2). Estimating the shear yield in a ductile material, ½ of the tensile-yield is often used (Ref. 3), giving 2000 psi (13.8MPa) shear strength for HDPE. For a single material, as in Core #1 (ignoring the bonding resin), the shear area of the webs multiplied by the appropriate shear strength of the webs estimates the shear capability of the cross section; because the shear stress in the core is nearly constant through the thickness. Given that the BMC segment wall thickness is nominally 0.045 inches (1.1mm), and there are 4 segment thicknesses across the present test beams (2 webs, and 2 per web), and those webs are 8 inches (0.2m) high, the shear capability of the cross section is estimated to be 2880 pounds (12.8kN). From this the shear strength of Core #1 is estimated to be 45 psi (0.31MPa).

Since there are 2 cross sections supporting the beam in a 3 point loading situation, the maximum load for the beam is estimated to be 5,760 pounds (25.7kN, 2 x the cross section capacity). This is within 8 pounds (36N) of the tested value (about 0.1% error), way too close for engineering accuracy, more attributable to good luck. Nevertheless, it is very encouraging to see the predicted value so close to the tested value.

Estimating Core #2 Shear Strength

It is more difficult to estimate the shear strength of Core #2 because the web is composed of two materials (actually three) HDPE skins on a CSM core, laminated with polyester resin. The web is therefore modeled as a laminate because the in-plane shear modulus of the component materials is significantly different; and we cannot simply add up the strength contribution from each component. We must use laminate theory, and invoke uniform (in-plane) shear strain in order to predict the proper sharing of stress between the various components.

First we will estimate some material properties. The 1.5 oz./sq.ft. (460gsm) CSM center layer was 0.030" (0.76mm) thick, indicating a fiber content of 42% by weight, and thus an in-plane shear modulus in the range of 600 ksi (4.1GPa, Ref. 4). Combining the CSM with two layers of HDPE at 0.045" (1.1mm) thick each, with in-plane shear modulus in the 70 ksi (0.48GPa) range, gives a load sharing distribution of 73% in the CSM and 27% in the HDPE. Further, considering that the CSM will fail before the HDPE, because the failure strain of the CSM is the lower of the two, the failure load is expected to be 36% higher that the CSM alone. Knowing this we can now make a strength estimate similar to Core #1.

Typical in-plane shear strength for the CSM at 42% fiber content is 10 ksi (68.9MPa, Ref. 4). At 0.030" (0.76mm) thick and 8" (0.2m) high, the failure shear load for one web is 2400 pounds (10.7kN) for the CSM alone. Increasing this value by 36% according to the previous argument gives 3264 pounds (14.5kN) for the web shear load at failure. Since there are 2 webs, and the section is 8" (0.2m) wide, the average shear strength of the core is estimated to be 102 psi (0.70MPa). Comparing this to the measured value of 121 psi (0.83MPa) indicates that the previous estimates were in a reasonable range. Core #2 is 20% stronger than predicted.

Core Density

The core density must include the weight of the segments as well as the resin and glass within the core. Core density was calculated by weighing the test samples, subtracting the weight of the skins, and dividing by the remaining volume. The test panels weighed 5.0 and 5.5 pounds (2.27 and 2.5 kg) for Core #1 and Core #2 respectively; giving a core density was 4.8 and 5.4 pounds per cubic foot (77 and 87 kg/m^3) respectively. These values are in the range of typical medium density PVC foam core.

Advantages and Disadvantages

Some of the possible advantages and disadvantages of this type of core material are summarized below.

Advantages:

- Commodity process to make segments, scaleable, and relatively low cost. Cost similar to HDPE bottles.
- Core provides webs in two mutually perpendicular directions.
- Able to easily provide thicknesses over 8 inches (0.2m).
- Segments can be molded with resin distribution grooves.
- Drop-in for many vacuum infusion processes.
- Difficult to peel skins off.
- Resists damage and delamination.

Disadvantages:

- Segment tooling/molds are relatively expensive.
- Segment tooling is generally restricted to one shape per mold.
- Production minimum quantities are typically 10k or more, making small runs difficult.
- Segments must be sealed to avoid crushing during vacuum infusion.
- Molding is tricky to avoid crushing segments, using extra resin, and compromising the structure.

Conclusions

Hollow blow molded segments were successfully molded into a sandwich panel configuration using vacuum assisted resin transfer molding. The predicted shear strengths of the fiber glass reinforced and un-reinforced panels were reasonably close to the test values. The shear strength and damage resistance of the two core samples tested was significant enough to warrant further investigation and characterization. This type of core material could provide a cost effective option for sandwich structures 8" (0.2m) thick and thicker.

Figure – 1, Exploded view showing skins top and bottom, and array of BMC hollow core segments assembled in-between.

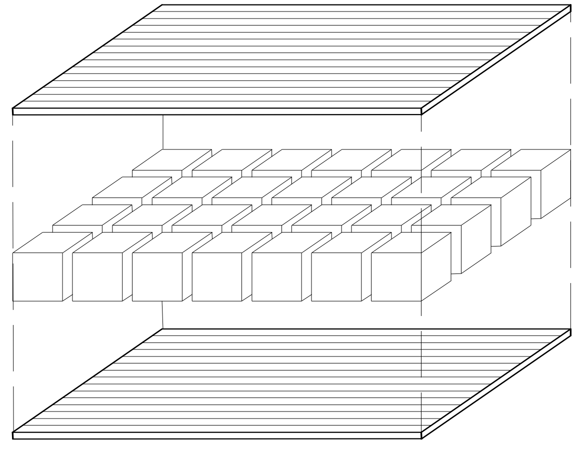
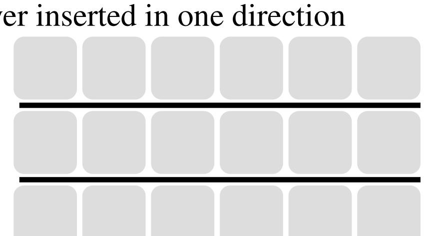


Figure - 2, Large segment 8”x 8” x 16”, small segment 4”x 4”x8”, segment wrapped with fiberglass fabric, and sandwich panel (bottom right).

Figure - 3, Three different core configurations viewed from the top.

1) BMC segments alone

2) BMC segments with fiberglass layer inserted in one direction



3) BMC segments wrapped with fiberglass on four sides

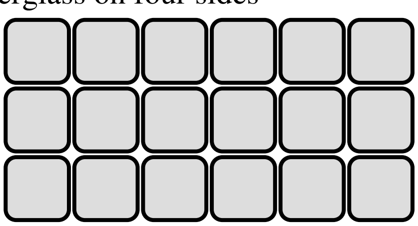


Figure - 4, Mold with CSM layers in the bottom for skin reinforcement, and BMC segments being loaded in on top.

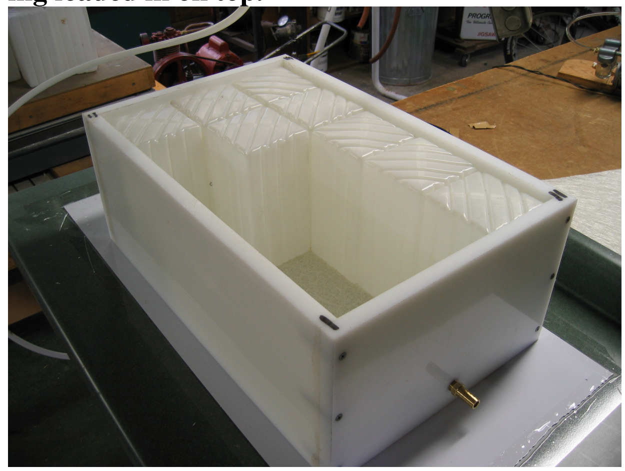


Figure - 5, Mold loaded with BMC segments, and covered with 2 layers 1.5 oz. CSM for the top skin. Note: resin inlet port bottom right.

Figure - 6, As-molded panel after vacuum infusion with polyester resin (3 segments wide x 5 long).

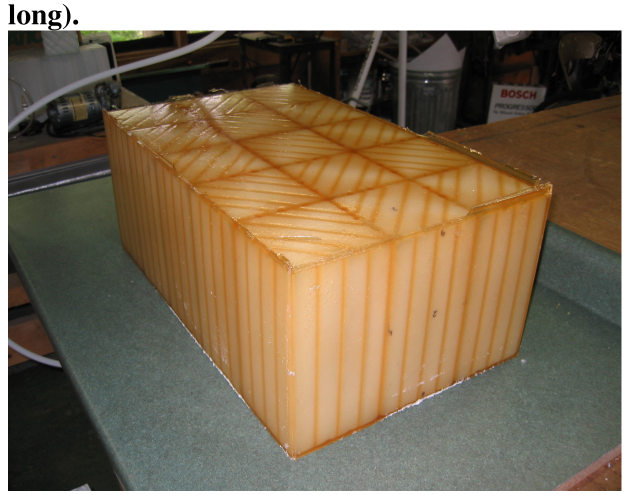


Figure - 7, Panel with edges removed and prepared for shear testing.

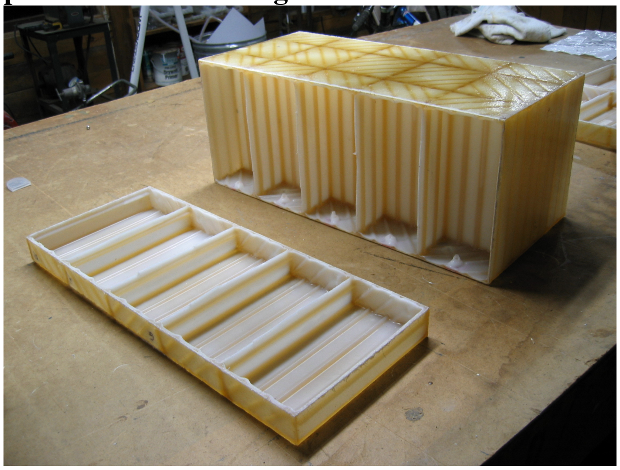


Figure - 8, Panel setup for 3-point shear test. This picture was actually after failure (Figure #9) with the load removed, the panel showed little sign of damage.

Figure - 9, Core #1 at failure (5600 pounds, 25kN, applied), note web buckling.

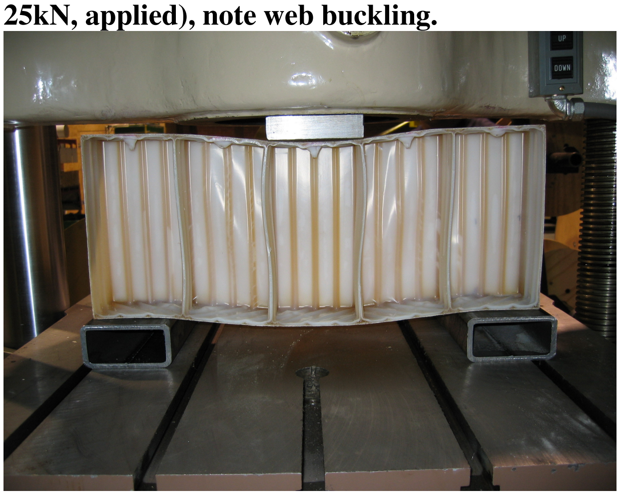
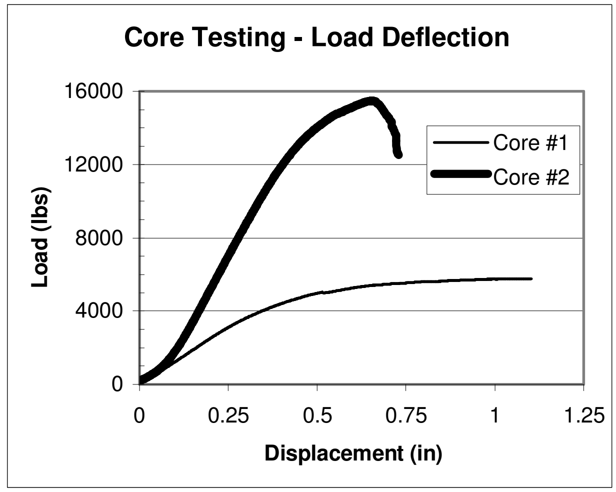


Figure - 10, Load-Deflection test curves.



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Steven J. Winckler, President, Global Composites, Inc. Steve has worked in the composites industry for the past 25 years, he holds 5 patents, and has published numerous journal papers on composite materials.