COMPRESSIVE STENGTH OF FOAM-FILLED HONEYCOMBS

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ABSTRACT

The present study considers filling of Nomex honeycomb cores with rigid foam to increase the compressive strength of the honeycomb. The long-term purpose of this is to create a multifunctional sandwich material. This sandwich structure will be a laminar construction comprising a combination of alternating dissimilar simple or composite materials (the foam-filled honeycomb being one of them), assembled and intimately fixed in relation to each other so as to use the properties of each to attain specific structural advantages for the whole assembly. One of the potential benefits of filling the honeycomb with rigid foam is the enhancement of damage resistance.

INTRODUCTION

Polymer foams and honeycombs are widely used in sandwich structures as a middle layer or core. Mechanical effectiveness of honeycombs is usually higher than effectiveness of foams of the same bulk density. The idea of combined core made from honeycombs filled by foams was studied in few works but was not used in practice due to elevated bulk density and complexity of the technology. This problem can be considered now under a new angle. Prospective application of composite sandwiches as walls of containers for liquid hydrogen and other gases demanding these structural elements to fulfill multiple functions: mechanical resistance, thermal isolation, and act as barrier. Combination of foams and honeycombs in one core can provide better combination of these different requirements and increase the safety of structure. Questions about comparison of mechanical effectiveness of honeycomb, foams, and foam-filled honeycombs remain open. In this stage of the project, the main mechanical property, transversal compressive strength was studied.

LITERATURE REVIEW

By: Hyo S. Lee, Soon H. Hong, Jara R. Lee, Yeung K. Kim

Mechanical behavior and failure process during compressive and shear deformation of honeycomb composite at elevated temperatures.

The mechanical behaviour and failure mechanisms of honeycomb composite consisting of Nomex honeycomb core and 2024A1 alloy facesheets were investigated. The compressive deformation behavior of honeycomb composite was progressed by an elastic and plastic buckling of cell walls, debonding fracture at the interfaces of cell walls, and followed by a fracture of resin layer on cell walls.

By: Wu C.L., Weeks C.A., Sun C.T.

Improving honeycomb-core sandwich structures for impact resistance

An aluminum honeycomb was filled with rigid foam to improve its mechanical properties. This foam-filled honeycomb was used to construct sandwich panels with graphite/epoxy composite face sheets. The mechanical properties of the foam-filled honeycomb were found to be superior to the unfilled honeycomb. Low velocity impact test results indicated that the sandwich panel containing the new core had much improved impact resistance and that the impact inflicted core crushing was highly localized.

By: Floyd P. Henry, General Plastics Mfg. Co.; Robert A. Johnson, Packaging Technology, Inc.; Peter Shih, Transnuclear, Inc.; Theodore Hile, General Plastics Mfg. Co.

A Comparison of Requirements and Test Methodologies for a Variety of Impact Absorbing Materials

One of the greatest attractions of rigid polyurethane foams is their nearly perfect isotropic crush property. On the other hand, all woods and honeycombs are highly anisotropic. The difference arises from the symmetrical cell shape of foams. Woods and honeycombs consist of aligned tubular cells, similar to a series of soda straws. Consequently the cell resists buckling in the direction parallel to the cells' long axis and is significantly weaker in the perpendicular direction. The orientation of the fibers combined with the close packing of the cells provides some resistance to buckling and gives woods and honeycombs the advantage of greater energy absorption than foams in the parallel orientation when compared at the same density.

CORE MATERIALS

The purpose of a core material in a sandwich structure is to increase the structure's stiffness by effectively making it thick using a low-density core material.

HONEYCOMBS

Honeycomb cores are available in a variety of materials for sandwich structures. Honeycombs can be processed into both flat and curved composite structures.

ALUMINIUM HONEYCOMB

They produce one of the highest strength/weight ratios of any structural material. These honeycombs are made by a multi-stage process. Despite its relatively low price and good mechanical properties, it has to be used with caution in marine structures because of its potential corrosion problems in a salt-water environment.

NOMEX HONEYCOMB

This is made by a multi-stage process. It is made by using Kevlar paper. Layers of this paper material are laid one on top of the other with lines of adhesive. Each layer has the adhesive lines in a different place. When the adhesive has set and the layers are expanded the honeycomb is formed. The initial paper honeycomb is usually dipped in a phenolic resin to produce a honeycomb core with high strength and very good fire resistance. The disadvantage of this honeycomb is that it is considerably more expensive than other core materials.

THERMOPLASTIC HONEYCOMB

They are usually produced by extrusion followed by slicing to thickness. They are usually light in weight, and are easier to recycle. Its major disadvantage is that it is difficult to get a good interfacial bond between the core and the skin.

FOAMS

Foams are relatively new forms of polymer-based materials. They are light in weight and versatile, and are employed increasingly in a variety of applications that include thermal and acoustic insulation, core materials for sandwich panels, fabrication of furniture and flotation materials. Foams are made by forming gas bubbles in the polymerizing mixture. This is called blowing.

FOAM TYPES

There are three foam types that, in quantity terms, are particularly significant:

1. Low density flexible foam: are materials composed of lightly cross-linked, open cells. As a result, air may flow through the structure very easily. These flexible foams are produced as slabstock or individually molded cushions and pads.
2. Low density rigid foams: are materials composed of highly cross-linked polymers with a closed cell structure. Each bubble within the material has unbroken walls so that gas movement is impossible. They offer good structural strength. Bases for

rigid foams are polymers having glass-transition temperatures higher than room temperature. The cells of rigid foam are about the same size and uniformity as those of flexible foam, but rigid foams usually consist of 90% closed cells. Compressing the foam beyond its elastic limit damages the cellular structure. For this experiment, Polyurethane and Polyether rigid foams were used. The polyether foam is a polyurethane pour foam.

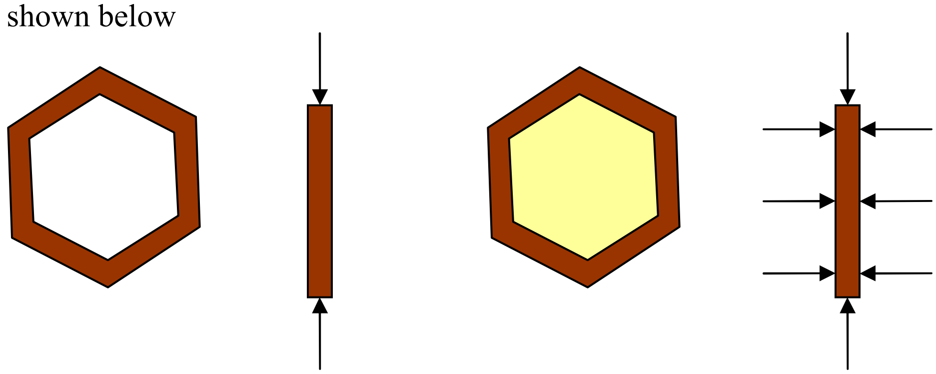
a. Polyurethane is a polymeric substance containing many urethane linkages.
b. Polyether is a polymer containing ether linkages.

3. High-density flexible foams: have densities above 100kg/m^3. These include molded self-skinning foams and microcellular elastomers.

EFFECTS OF FOAM-FILLED HONEYCOMBS

All these happen when foam-filled honeycombs are compared with plain honeycombs.

1. Walls carry load on plain honeycomb but with foam-filled honeycombs, the load is also carried by the foams in the cell.
2. The foam in the foam-filled honeycombs creates supporting reaction for the wall as shown below



a) Plain honeycomb b) Foam-filled honeycomb

3. The integrated layer called the integral form works like honeycombs impregnated with polymer and as a result increases the moment of inertia and cross section of the wall. This is because foams are denser when closer to the wall.

METHODOLOGY

APPARATUS

- Nomex Honeycomb with hexagonal cell shape
- Polyurethane foam mixtures A and B
- Polyether foam mixtures A and B
- Band saw
- Universal Testing machine – INSTRON Model 4467
- Balance with accuracy to 0.01g
- Meter Rule
- (2) 1000ml plastic beaker

PROCEDURE

MAKING SAMPLES

1. Twelve 2”x2”x1” samples of the Nomex honeycomb were measured using the meter rule and cut using the band saw.
2. Each of the twelve samples was labeled and then weighed using the balance and recorded.
3. 100g of Polyurethane foam mixture A was measured into the beaker.
4. 100g of Polyurethane foam mixture B was measured and also added to the same beaker.
5. The mixture in the beaker was stirred for 55 seconds.
6. Four 2”x2”x1” Nomex honeycomb samples were immersed quickly in the mixture and brought out using a plastic fork one.
7. The samples were placed on a clean, dry surface.
8. The excess mixture was left in the beaker to begin foaming.
9. After the reaction had occurred, the excess foam on the honeycombs was cut off using the band saw.
10. The four samples were once again weighed and recorded.
11. The foam in the beaker was brought out and four 2”x2”x1” samples were measured and cut out using the band saw.
12. The four samples were recorded and weighed.

13. 100g of Polyether foam mixture A was measured into the second beaker.
14. 100g of Polyether foam mixture B was measured and also added to the same beaker.
15. The steps from 5 to 12 were followed.

TESTING SAMPLES

1. The computer was connected to the INSTRON machine.
2. In the INSTRON program on the computer, compression test was selected and the format modified to the required units and type of results.
3. The four plain honeycomb samples were tested and the results printed.
4. The four polyurethane foam samples were tested and the results printed.
5. The four polyurethane foam-filled honeycomb samples were tested and the results printed.
6. The four polyether foam samples were tested and the results printed.
7. The four polyether foam-filled honeycomb samples were tested and the results printed.

RESULTS

Table 1 Data obtained from the samples
Density is in (g/in^3)

	Sample	*Maximum Load (lbf)*	*Compressive Strength (ksi)*	*Mass (g)*	*Density*		
2 LB DENSITY POLYETHER FOAMS	A	166.23	0.04	2.7029	0.7113		
	B	145.78	0.04	2.7000	0.7105		
	C	109.54	0.03	2.3492	0.6182		
	D	104.38	0.03	2.3365	0.6149		
4 LB DENSITY POLYURETHANE FOAMS	A	477.43	0.13	6.8817	1.8110		
	B	500.78	0.13	6.5590	1.7261		
	C	504.00	0.13	7.2533	1.9088		
	D	552.17	0.15	7.3267	1.9281		
PLAIN HONEYCOMB	A	2157.59	0.57	5.7944	1.5248		
	B	2805.91	0.74	6.0306	1.5870		
	C	2784.97	0.73	6.4171	1.6887		
	D	2197.86	0.58	6.0385	1.5891		
	Sample	*Maximum Load (lbf)*	*Compressive Strength (ksi)*	*BEFORE FILLING*		*AFTER FILLING*	
				Mass(g)	*Density*	*Mass (g)*	*Density*
2 LB DENSITY POLYETHER FOAM-FILLED HONEYCOMB	A	2710.88	0.71	6.441	1.695	9.893	2.603
	B	3522.69	0.93	6.406	1.686	9.791	2.577
	C	3595.17	0.95	5.758	1.515	9.135	2.404
	D	3715.98	0.98	6.690	1.760	10.295	2.709
4 LB DENSITY POLYURETHANE FOAM-FILLED HONEYCOMB	A	3411.55	0.90	6.195	1.630	15.216	4.004
	B	3910.88	1.03	6.406	1.686	14.971	3.940
	C	3472.76	0.91	6.534	1.719	14.482	3.811
	D	4241.08	1.12	6.256	1.646	14.283	3.759

Fig 1 The mean maximum load of each group of samples

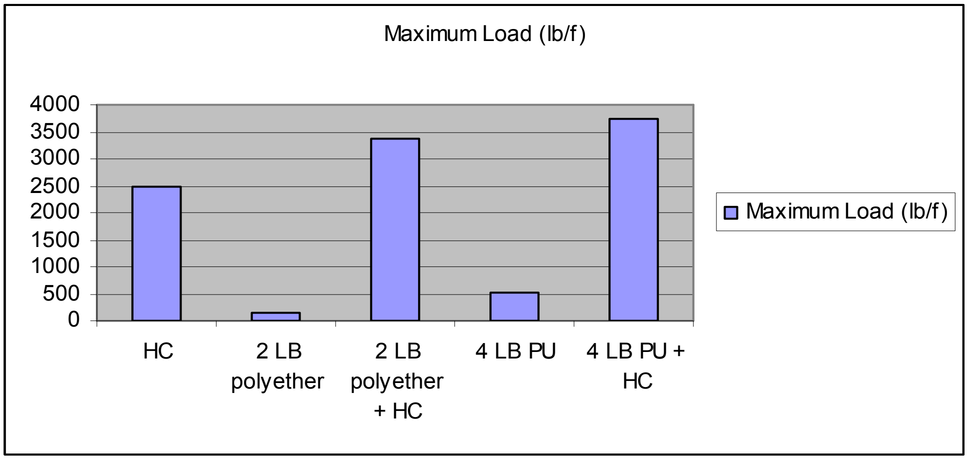
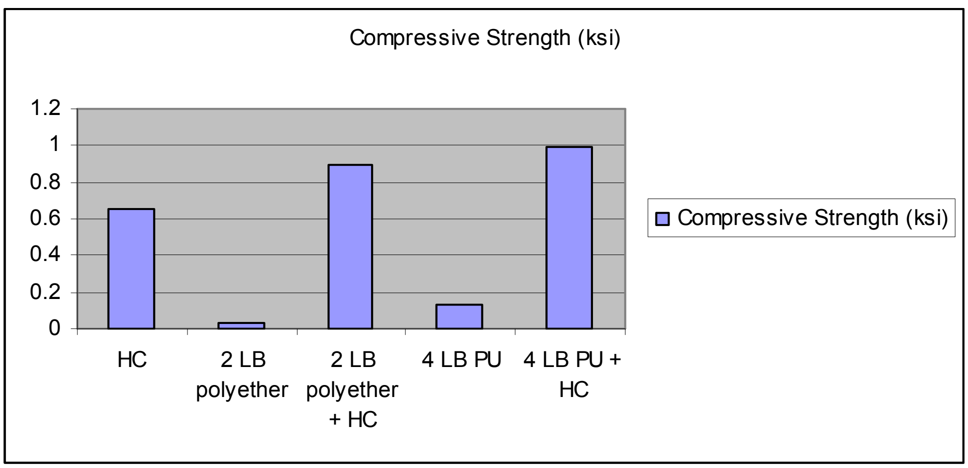


Figure 2 The mean compressive strength of each group of samples



DISCUSSION OF RESULTS

When comparing the plain honeycombs to foam-filled honeycombs, as seen in the two charts above, it is obvious that plain honeycombs have a relatively high compressive strength and a higher maximum load capacity than foams. But when the honeycombs were filled with foams, both the compressive strength and maximum load capacity of the foam-filled honeycombs were greatly increased.

Also,

Comparison of plain honeycomb to 2lb density polyether rigid foam-filled honeycomb:

Percentage increase in Maximum Load = (3386.18-2486.58)/2486.58 = 36.2%

Percentage increase in Compressive Strength = (0.89-0.65)/0.65 = 36.9%

Percentage increase in mass = (9.7787-6.0702)/6.0702 = 61.1%

Comparison of plain honeycomb to 4lb density polyurethane (PU) rigid foam-filled honeycomb:

Percentage increase in Maximum Load = (3759.07-2486.58)/2486.58 = 51.2%

Percentage increase in Compressive Strength = (0.99-0.65)/0.65 = 52.3%

Percentage increase in mass = (14.7381-6.0702)/6.0702 = 142.8%

As seen in the calculations above, when using the 4lb density rigid foam, we were able to increase the compressive strength of the honeycomb up to 50%, but the mass was increased to almost 3 times the mass of the plain honeycomb. On the other hand, with the 2lb density rigid foam, we were able to increase the compressive strength to 37% and the mass was not increased even up to 2 times the mass of the plain honeycomb.

CONCLUSION

If high mass is a problem, a low-density rigid foam can always be used when making foam-filled honeycombs since in combination of honeycombs and forms, resistance to compression is determined by honeycombs mainly because forms buckle more under compressive stress. The foams can be smashed till it is very thin, but for honeycombs it depends on the buckling of the cells.

BIBLIOGRAPHY

Beyle, Andrey. Senior Research Faculty, CNCMM

Blaga, A. "CBD-166. Plastic Foams." Canadian Building Digest 01 Jan. 1974
http://irc.nrc-cnrc.gc.ca/cbd/cbd166e.html

Floyd P. Henry, General Plastics Mfg. Co.; Robert A. Johnson, Packaging Technology, Inc.; Peter Shih, Transnuclear, Inc.; Theodore Hile, General Plastics Mfg. Co. "A Comparison of Requirements and Test Methodologies for a Variety of Impact Absorbing Materials." PATRAM International Symposium, Chicago, IL; September, 2001

Hyo S. Lee, Soon H. Hong, Jara R. Lee, Yeung K. Ki; "Mechanical behavior and failure process during compressive and shear deformation of honeycomb composite at elevated temperatures.";Journal of Materials science 37 (2002) 1265-1272

Woods, George. THE ICI POLYURETHANES BOOK 2nd Edition, New York, NY: John Wiley & Sons, 1990

Wu C.L., Weeks C.A., Sun C.T."Improving honeycomb-core sandwich structures for impact resistance.";Journal of Advanced Materials, v 26, n 4, Jul, 1995, p 41-47

http://www.favonius.com/soaring/foams/foams.htm

http://www.formulaschools.com/curriculum/corematerials.htm

http://www.machinedesign.com/BDE/materials/bdemat2/bdemat2_25.html

http://www.tricelcorp.com/exhibits/specs.htm