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Drop Weight Testing on Sandwich Panels with a Novel Thermoplastic Core Material

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Keywords
sandwich panels, impact loading, drop weight tests, energy absorption, thermoplastics

Introduction

Conventionally, sandwich panels are made up of two stiff and strong facings separated by a lightweight core. While aluminum and fiber-reinforced plastics are commonly used for the facings of sandwich construction, the core is generally made from monolithic materials in a repeated cell pattern. The development of lightweight, high-strength core materials has led to potential applications for blast resistance. For instance, these sandwich panels can be airlifted to forward bases where shelters or protective structures can be constructed expediently with

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A series of drop weight tests were conducted to evaluate the dynamic flatwise compression strength and flexural strength of sandwich panels with a novel core structure. This sandwich core material, known as Norcore, consists of interconnected cells in a unique configuration of truncated pyramid with sloping cell walls. Core materials made of thermoplastic including virgin Lexan, polycarbonate, polycarbonate regrind, high-impact polystyrene, and acrylonitrile butadiene styrene were tested. The test results showed that these sandwich panels have good strength as well as energy absorption capacities.

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Introduction

Conventionally, sandwich panels are made up of two stiff and strong facings separated by a lightweight core. While aluminum and fiber-reinforced plastics are commonly used for the facings of sandwich construction, the core is generally made from monolithic materials in a repeated cell pattern. The development of lightweight, high-strength core materials has led to potential applications for blast resistance. For instance, these sandwich panels can be airlifted to forward bases where shelters or protective structures can be constructed expediently with

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indigenous materials and labor. In this case, the strength/stiffness-to-weight ratio and impact energy absorption capacity are essential design parameters. Gibson and Ashby [1] provide detailed design guidelines for sandwich panels based on the failure modes including face yielding, face wrinkling, core failure, and delamination of facing from the core.

In this paper, the dynamic strength of a novel sandwich panel structure due to the impact of a drop weight was studied in detail. The results are compared to the static test results published in the literature. The tests conducted are the ASTM C365 – flatwise compressive strength and the ASTM D790 – three-point loading flexural strength tests. The impact energy absorption capacities of several thermoplastic core materials are presented.

Novel core cell structure

A core material, known as Norcore [2], is manufactured by stretching a thin solid sheet of thermoplastic placed between two heated die plates. This core material has features of both a dense elastic solid and those of a foam-type material. This novel cellular structure is similar to a traditional honeycomb core and that of an egg crate. Due to the forming process used in creating this sandwich core material, it is possible to control the cell wall thickness and relative density associated with cellular structure configurations. Figure 1(a) and (b) shows the top view and the edge view of a typical Norcore panel, respectively. Tuan and Sierakowski [3] studied the unique cell geometry of Norcore and compared finite element simulation results with test data.

The fabrication process of these core panels is shown in Figure 2. The vents are used to create a vacuum between the plates. The cell structure of the core resulting from this process is a series of interconnected truncated cones. These cores have variable cell thickness, strength, and stiffness, the selection of which is dependent upon a particular application. The stretched core thus formed has a stiffness of 50 to 100 times that of the original extruded sheet, and with the addition of facings, the resultant sandwich construction may have a stiffness of 300 to 1000 times that of the original extruded sheet. Some of the physical and mechanical properties of these sandwich panels with aluminum facings from the manufacturer are given in Table 1.

Drop weight tests

Drop weight testing facility

A drop weight testing facility is set up in the Structural Research Laboratory at the Peter Kiewit Institute, Omaha, Nebraska. The setup was designed to deliver impulsive loading onto a test specimen. As shown in Figure 3, the facility is composed of a strong foundation, steel supports, a strong wall, a PVC pipe drop chute, and a drop weight.

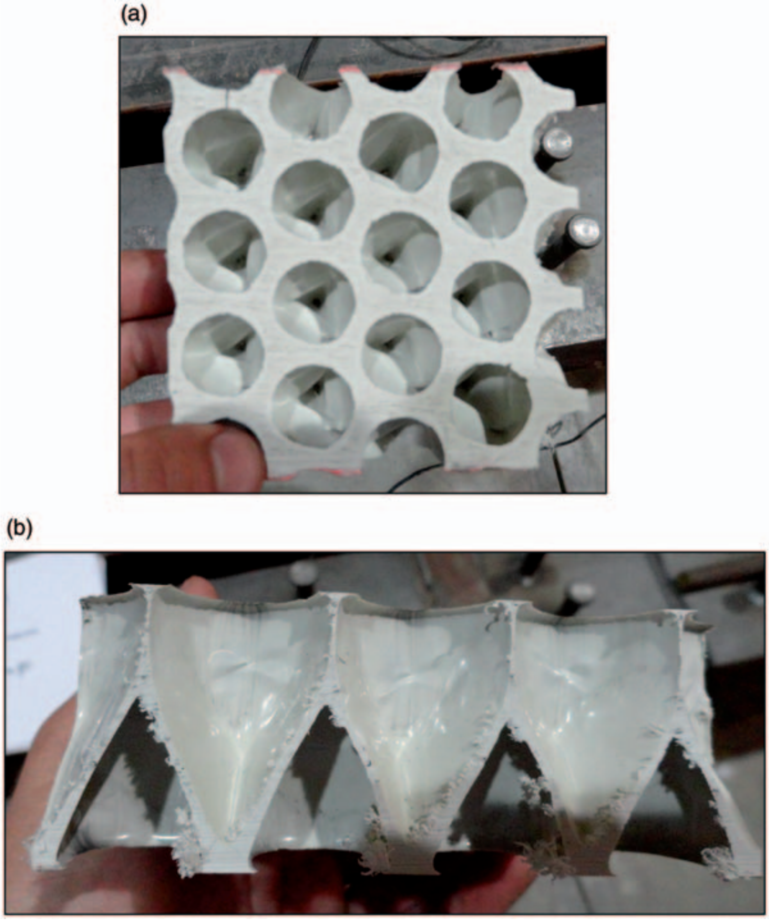

Figure 1. Cell structure of Norcore. (a) Top View (b) Edge View.

The steel supports are firmly fixed to the foundation. The drop weight is made of a 5.625-in. (143 mm) diameter steel cylinder and a 1.5-in. (38 mm) steel rod welded to the end for impact tup. The cylinder had four skids welded at equidistance along the surface as stabilizers in the PVC drop chute. One-inch (25 mm) holes are drilled along the PVC pipe at 2-, 3-, 4-, and 5-ft (0.6, 0.9, 1.2, and 1.5 m) drop heights. The total weight of the drop weight is 72.3 pounds (321.6 N). The drop weight is lowered into the drop chute at a drop height by means of a rope going over a pulley. The drop weight can be quickly released by detaching the rope from the anchor on the concrete floor. The drop weight tests conducted were the flatwise compressive strength and three-point simple beam flexural strength tests. The specimens used for the flatwise compressive strength drop weight tests were 1-in.

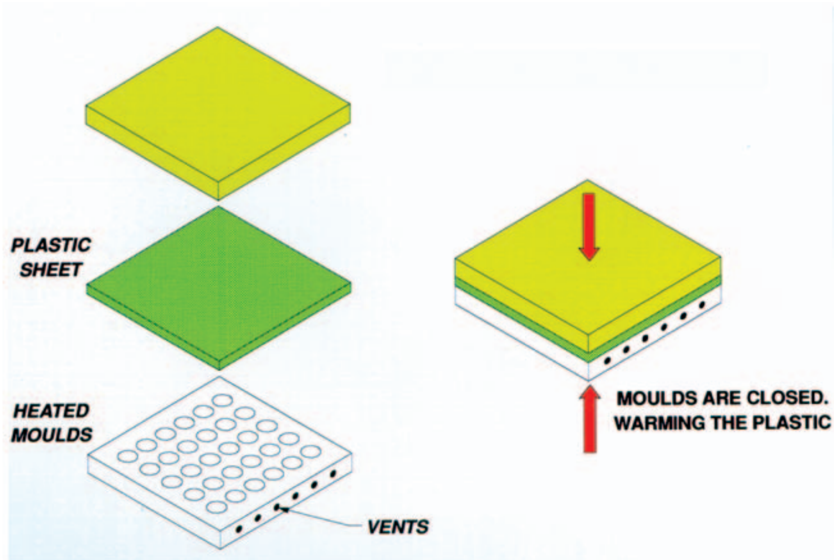

Figure 2. Fabrication process of Norcore.

Table 1. Mechanical properties of 1-in. Norcore core with 0.023-in. aluminum facings

Property	ASTM test	Units	HIPS	PC	ABS
Flexural strength[a]	D790	Psi	343	587	—
Flexural strength	D790	Psi	1146	1538	1897
Flexural modulus	D790	Psi	317,000	210,000	431,000
Shear strength	C393	Psi	105	142	170
Shear modulus	C393	Psi	5000	3100	7000
Flatwise compressive					
Ultimate load	C365	Lb	3990	2620	—
Strength	C365	Psi	250	164	—
Edgewise compressive					
Strength[a]	C364	Psi	167	199	—
Strength	C364	Psi	16,200	14,270	—

ABS: acrylonitrile butadiene styrene; HIPS: high-impact polystyrene; PC: polycarbonate; 1 in. = 25.4 mm; 1 psi = 6.9 kPa; and 1 lb = 4.45 N.
[a]Test data without facings.

(25 mm) or 1.5-in. (38 mm) thick, 4 in. by 4 in. (102 mm × 102 mm) square panels without facings, and those for the bending tests are 12 in. (305 mm) long and 4 in. (102 mm) wide core with 0.032-in. (0.81 mm) aluminum facings. These test specimens were supplied by the manufacturer.

Figure 3. Drop weight testing setup.

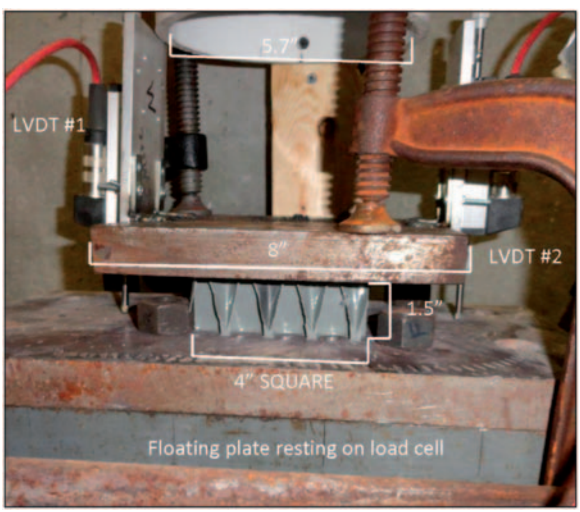

Figure 4. Flatwise compression test setup.

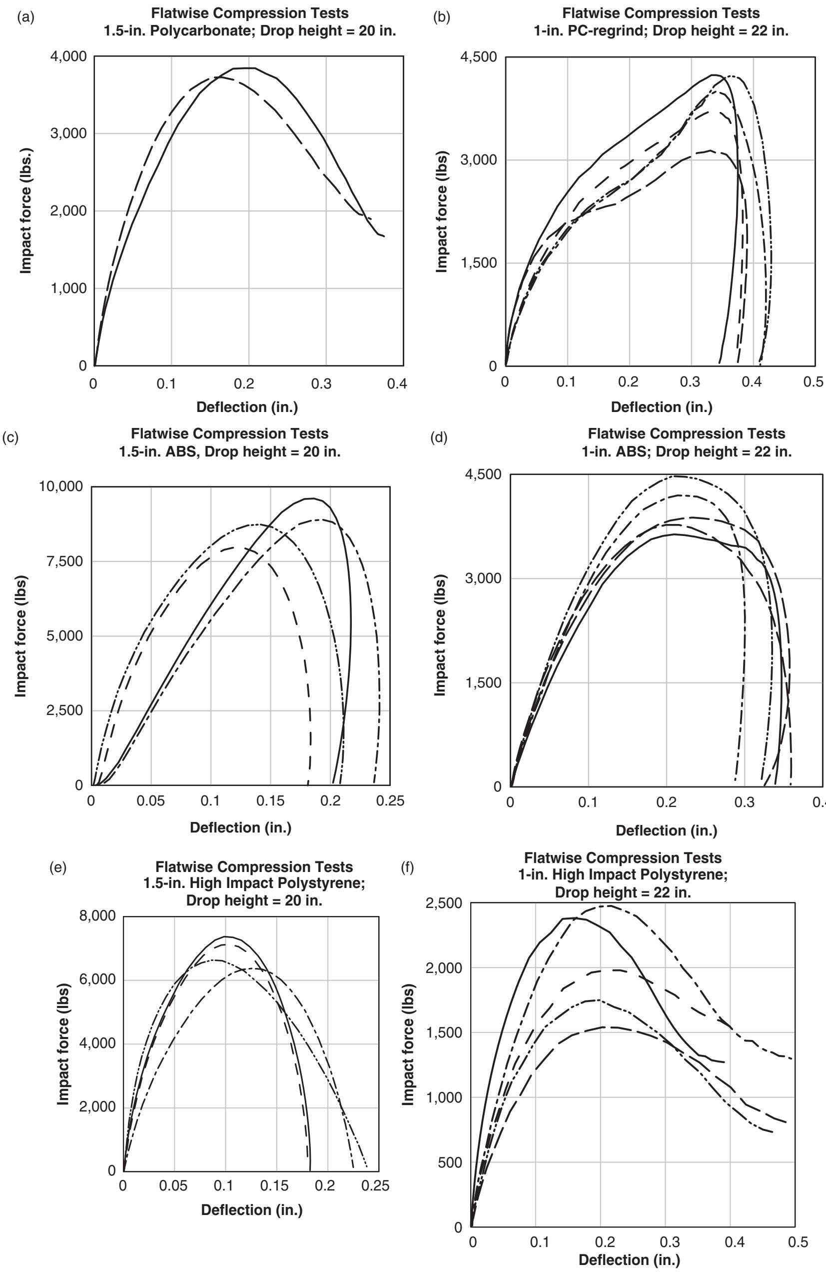

Figure 5. (a) 1.5-in. thick polycarbonate (PC); (b) 1-in. thick PC-regrind (PCR); (c) 1.5-in. thick acrylonitrile butadiene styrene (ABS); (d) 1-in. thick ABS; (e) 1.5-in. thick high-impact polystyrene (HIPS); and (f) 1-in. thick HIPS.

Table 2. Flatwise compression drop weight test results

Core material	Core height (in.)	Drop height (in.)	Peak stress (psi)	Impact energy (in.-lbs)	Energy absorption (in.-lbs)	Energy absorption (%)
Polycarbonate (PC)	1.5	24	240	1735	1045	60
Polycarbonate (PC)	1.5	24	233	1735	994	57
Polystyrene (HIPS)	1.5	20	461	1446	980	68
Polystyrene (HIPS)	1.5	20	446	1446	934	65
Polystyrene (HIPS)	1.5	20	398	1446	1002	69
Polystyrene (HIPS)	1.5	20	415	1446	1090	75
Polystyrene (HIPS)	1.5	20	487	1446	1091	75
ABS	1.5	20	601	1446	1260	87
ABS	1.5	20	498	1446	1040	72
ABS	1.5	20	556	1446	1330	92
ABS	1.5	20	546	1446	1358	94
ABS	1.5	20	549	1446	751	52
PC-regrind	1.5	20	233	1446	1370	95
PC-regrind	1	22	265	1591	1143	72
PC-regrind	1	22	232	1591	1012	64
PC-regrind	1	22	250	1591	1091	69
PC-regrind	1	22	264	1591	1169	73
PC-regrind	1	22	196	1591	924	58
Polystyrene (HIPS)	1	22	149	1591	702	44
Polystyrene (HIPS)	1	22	124	1591	636	40
Polystyrene (HIPS)	1	22	155	1591	887	56
Polystyrene (HIPS)	1	22	109	1591	588	37
Polystyrene (HIPS)	1	22	96	1591	572	36
ABS	1	22	227	1591	968	61
ABS	1	22	242	1591	1065	67
ABS	1	22	262	1591	929	58
ABS	1	22	280	1591	1125	71
ABS	1	22	236	1591	1016	64

ABS: acrylonitrile butadiene styrene; HIPS: high-impact polystyrene; 1 in. = 25.4 mm; 1 psi = 6.9 kPa; and 1 in-lb = 0.113 J.

Flatwise compression tests

A compression test specimen placed between two rigid steel plates is shown in Figure 4.

The total downward force during a drop weight test was monitored by a 200-kip (890 kN) load cell. Two linear variable differential transformers (LVDTs) were used to measure the relative displacement between the two steel plates. The average displacement is taken as the contraction in the core material. Strain gages were also mounted on the webs of some specimens to estimate the strain rate of the drop weight impact loading. C-clamps were used to snugly hold the top steel plate to prevent it from rebounding after impact. The strain, displacement, and force data traces were recorded by a data acquisition system at a sampling frequency of 4000 Hz.

Figure 5(a) through (f) shows the load-deflection curves of different Norcore materials from the flatwise compression drop weight tests. The area under a load-deflection curve represents the capacity of impact energy absorption of the core material. The initial energy of the drop weight before impact, calculated as the drop weight times drop height, and the energy absorption capacities are presented in Table 2.

A failed 1.5-in. (38 mm) thick, high-impact polystyrene (HIPS) core is shown in Figure 6. One 1.5-in. HIPS and one 1.5-in. acrylonitrile butadiene styrene (ABS) specimens had a strain gage mounted vertically on the web to measure the strain rate. The strain rate appeared to be dependent upon the stiffness of the core materials. As shown in Figure 7, the peak strain rate in the ABS was about 11/sec at 0.002 sec and that in HIPS was about 3/sec at 0.003 sec after impact.

Three-point bending tests

All the sandwich panel specimens under bending drop weight tests were 12 in. (305 mm) long and 4 in. (102 mm) wide core with 0.032-in. (0.81 mm) aluminum facings. The clear span between the simple supports was 9 in. (229 mm). The 1.5-in. (38 mm) overhang at each end of the specimen was free to rotate. The test specimens were impacted at the mid-span by the drop weight. Two strain gages were mounted on the top facing at 2-in. (51 mm) distance on either side of the mid-span, and two strain gages were mounted on the bottom facing at the mid-span. The displacement at the mid-span is monitored by a string potentiometer. Some specimens had additional strain gages mounted on the web at the mid-span to monitor

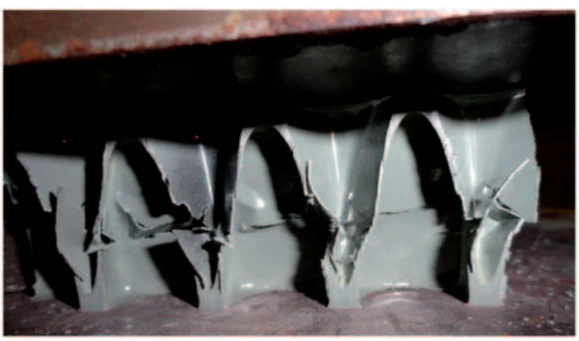

Figure 6. Failed high-impact polystyrene (HIPS) core under flatwise compression.

the strain rate. Figure 8(a) shows a specimen before impact of the drop weight and Figure 8(b) shows the specimen after the impact.

Most common failure modes under a three-point bending test are local buckling or wrinkling in the top face, local yielding in the bottom face, crushing of

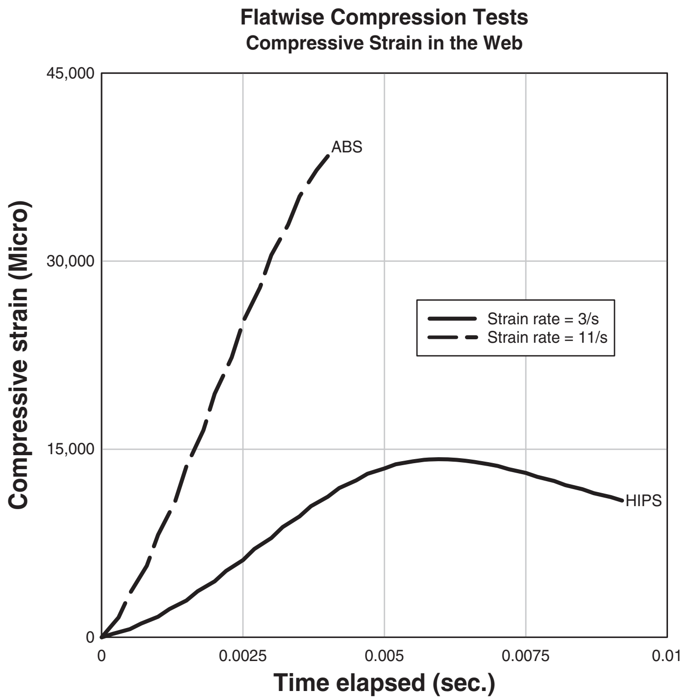

Figure 7. Strain rate of the flatwise compression drop weight tests.

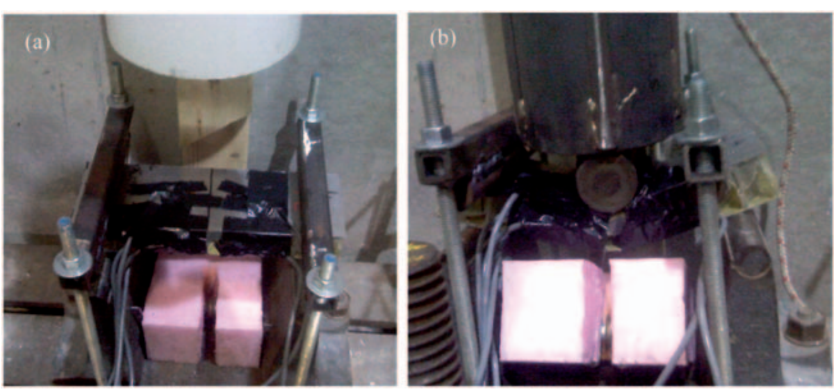

Figure 8. Drop weight bending test setup.

the core material, and bond failure between facing and the core, as shown in Figure 9.

The sandwich panels had 1.5-in. thick core made of polycarbonate, HIPS, ABS, and virgin Lexan. The load-deflection curves obtained from the drop weight

Figure 9. Failure modes observed in the flexural test.

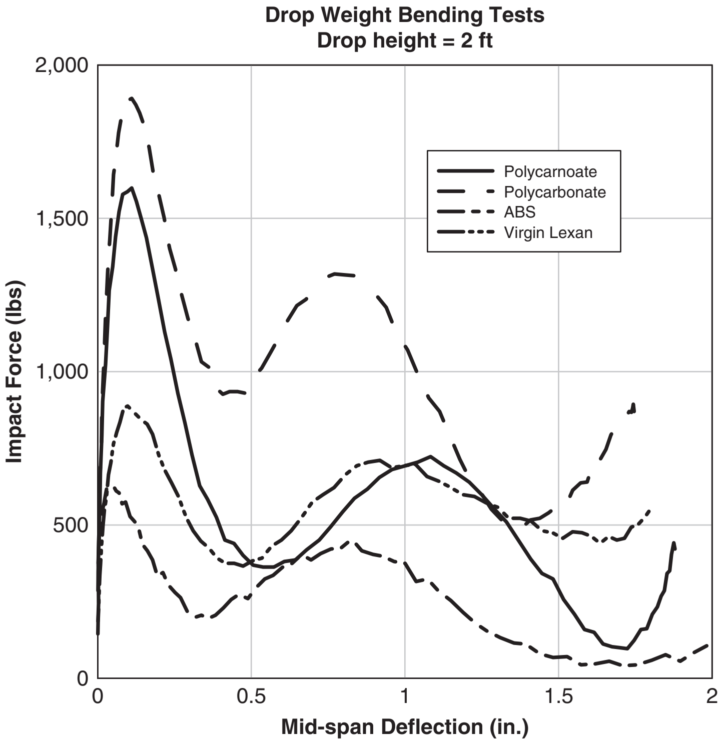

Figure 10. Load-deflection curves.

bending tests are compiled in Figure 10. The string potentiometer malfunctioned during the test of HIPS panel. It is evident that all the sandwich panels had fairly good strength and ductility for impact loading. The maximum mid-span deflection sustained was generally about 2 in., taking place within 0.02–0.03 sec after impact. The undulations in the impact force (or support reactions) were probably due to oscillations of the beam after making contact with the drop weight.

Aluminum has an elastic modulus of 10×10^6 psi (69 GPa) and a yield point of 30–35 ksi (207–241 MPa). The tensile strains in the bottom face obtained are presented in Figure 11, where the bottom face yielded when the tensile strains reached about 3500 micro strains.

The compressive strains in the top face obtained are presented in Figure 12, where local wrinkling occurred in the face when the compressive stresses reached about 4 ksi (28 MPa).

The strain rate of the drop weight bending tests can be estimated from the strain gages mounted vertically on the web of the sandwich core at the mid-span. The compressive strains thus obtained are presented in Figure 13. The strain rates obtained from the bending tests are remarkably close to those obtained in the

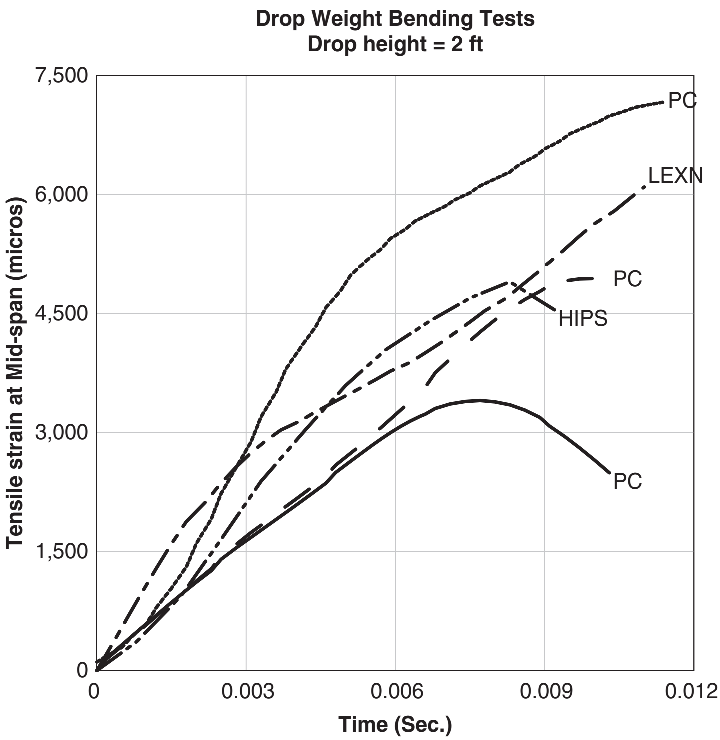

Figure 11. Tensile strains in the bottom face at mid-span.

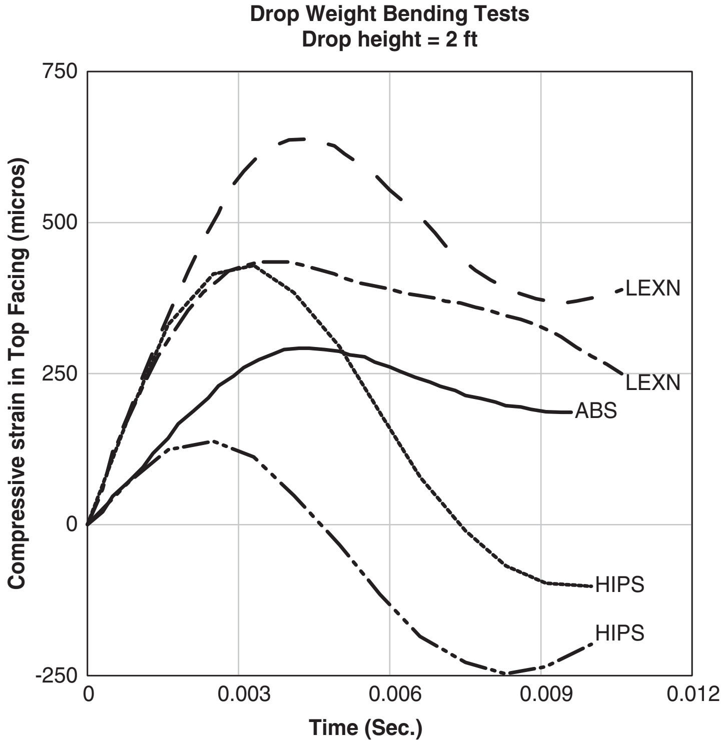

Figure 12. Compressive strains in the top face.

flatwise compression tests. The peak strain rate in the HIPS and Lexan was about 11/sec at 0.002 sec and that in PC was about 8/sec at 0.001 sec after impact.

Discussions

Sierakowski and Hughes [4] conducted a series of static flatwise compression and beam-bending tests on the sandwich panels with the Norcore materials. They also reported the results from dynamic compressive tests by using a Split Hopkinson Pressure Bar (SHPB). The average values from the drop weight tests are compared with their test results in Table 3. The flatwise compression drop weight test results compare fairly well with the SHPB test data, while the static test results are much higher in many cases. This could be due to early buckling of the web upon initial high-impact stress (see Figure 6), while the instability is delayed under static loading. On the contrary, the static bending test results [4] are lower than the drop weight test results and the published data by the manufacturer [2].

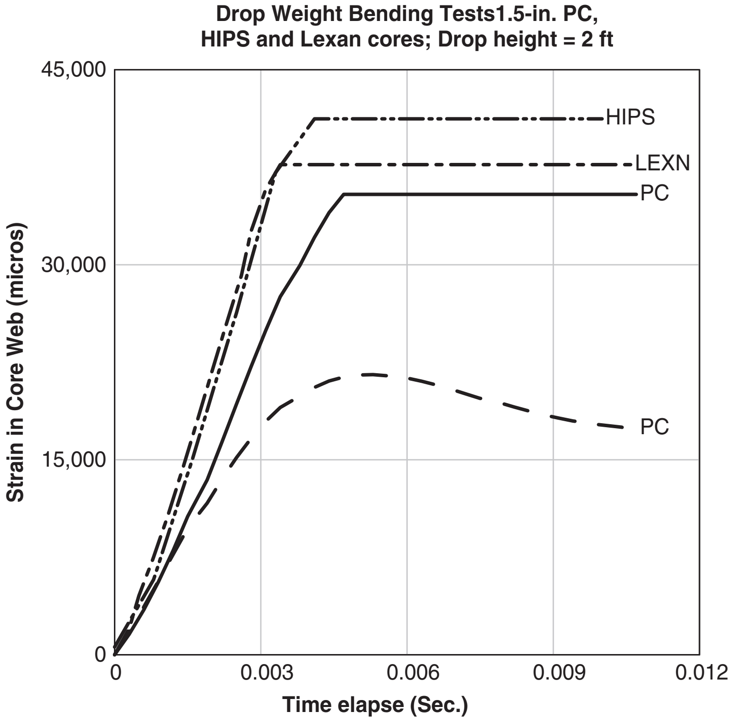

Figure 13. Compressive strains in the core web.

Table 3. Comparisons of drop weight test results vs. static test results [4].

		Flatwise compression tests (psi)			Beam Bending Tests (lbs)		
Core material	Core height (in.)	Drop weight	Static [4]	SHPB	Drop weight	Static [4]	Static [2]
Polycarbonate (PC)	1.5	235	143	348	1745	448	1538
PC-regrind	1	241	418	235	—	501	—
PC-regrind	1.5	233	439	235	—	1103	—
Polystyrene (HIPS)	1	127	658	—	690	655	1146
Polystyrene (HIPS)	1.5	441	473	493	—	462	—
ABS	1	249	605	410	—	726	1897
ABS	1.5	550	815	484	—	1653	—

ABS: acrylonitrile butadiene styrene; HIPS: high-impact polystyrene; SHPB: Split Hopkinson Pressure Bar; 1 in. = 25.4 mm; 1 psi = 6.9 kPa; and 1 lb = 4.45 N.

Conclusion

The dynamic strength of a novel sandwich panel structure due to the impact of a drop weight was studied in detail. The results are compared to the static test results published in the literature. The drop weight tests were conducted in accordance with the ASTM C365 – flatwise compressive strength and the ASTM D790 – three-point loading flexural strength tests. The initial impact energy of the drop weight and the impact energy absorption capacities of several thermoplastic core materials are presented. The percentage energy absorption shows that, for the same core material, the 1.5 in. (38 mm) core absorbed more impact energy than the 1-in. (25 mm) core did.

The test results have shown that these sandwich panels have good strength as well as good energy absorption capacities. The drop weight tests are easy to conduct and the tests are repeatable and reliable. Further drop weight testing should be conducted on sandwich panels with conventional core construction to compare impact energy absorption and weight savings characteristics against those of the Norcore panels.

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