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Experimental study of low velocity impact response of composite honeycomb core sandwich beams.

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Abstract:

The aim of this research is to investigate the low-velocity impact response of different types of sandwich beams. The test beams were subjected to low- velocity impact loading using drop mass setup, at three energy levels. The data were collected for each specimen, which included time, force, deflection, and energy.

The absorbed energy was evaluated and compared for different types of sandwich beams. Qusi-static tensile and flexural tests were performed to obtain the mechanical properties of the face sheets and the core. The results showed that the specimens with face sheets of fiber at 90 had the maximum peak impact force and deflection, while the specimens with face sheet of random fiber had the minimum peak impact force and deflection. Concerning the absorbed energy, it was maximum in the specimens with random fiber face sheets and minimum in the type with unidirectional fiber 90 face sheets.

Key wards: low velocity impact, sandwich beams, honeycomb core, impact force, absorbed energy.

الخلاصة:

إن هدف هذا البحث هو التحقق من سلوك أنواع مختلفة من عتبات الساندوج (sandwich beams) عند تعرضها لاصطدام واطئ السرعة. تم تعريض عتبات الفحص لتحميل اصطدام واطئ السرعة بواسطة الكتلة الساقطة سقوطا حرا وبثلاث مستويات لطاقة الاصطدام. تم جمع البيانات لكل عينة وقد تضمنت هذه البيانات الوقت وقوة الاصطدام والتشوه وطاقة الاصطدام.

تم حساب قيم الطاقة الممتصة ومقارنتها للأنواع المختلفة من عتبات الساندوج. أجريت اختبارات شد وانحناء شبه سكونية للحصول على الخصائص الميكانيكية لصفائح الوجه وللجزء الوسطي للعتبات. أظهرت النتائج أن العتبات ذات الصفائح الوجهية التي تحتوي ألياف موجهة بزاوية 90 حازت أعلى القيم لقوة الاصطدام القصوى والتشوه الأقصى، بينما حازت العتبات ذات الصفائح الوجهية التي تحتوي ألياف عشوائية اقل قيم لقوة الاصطدام القصوى والتشوه الأقصى. وبخصوص الطاقة الممتصة في الاصطدام، فقد كانت أقصى قيمها في العتبات ذات الصفائح الوجهية التي تحتوي ألياف عشوائية بينما كانت اقل قيمها في العتبات ذات الصفائح الوجهية التي تحتوي ألياف موجهة بزاوية 90.

1. Introduction:

Sandwich structures provide an efficient method to increase bending rigidity without a significant increase in structural weight. They enjoy high superior bending stiffness, low weight, excellent thermal insulation, acoustic damping, ease of machining, corrosion-resistance and stability. Due to these properties, composite sandwich structures are widely used in the aerospace, marine, aeronautics, automotive and recreational industries[Tomasz Lendze, et.al., 2006].

Several studies are made of sandwich structures impact and perforation behavior, T.Anderson and E. Madenci [T. Anderson, and E. Madenci, 2000] conducted impact tests to characterize the type and extent of the damage observed in a variety of sandwich configurations with graphite/epoxy face sheets and foam or honeycomb cores and this study showed that as the impact energy increased, the samples experienced one of two types of damage: tear or crack from the center of the laminate to the edge, or significant damage consisting of a dent localized in the region of impact. M. Meo, et.al. [M. Meo, et.al., 2003] found that numerical simulation of impact test on sandwich panels of carbon epoxy facing and nomex core was able to predict dent depth with an error of 2.6% and delamination area with an error of 10.5%. Md. Akil Hazizan and W.J. Cantwell [Md. Akil Hazizan, and W.J. Cantwell, 2003] investigated the low velocity impact response of two glass fiber/epoxy face sheets and aluminum honeycomb core sandwich structures. It was found that the partition of the incident energy depended strongly on the geometry of the impacting projectile. M. Meo et. al [M. Meo, et.al., 2005] made an experimental investigation and a numerical simulation on the low velocity impact damage of a range of sandwich panels. They consist of carbon/epoxy facing and nomex honeycomb cores. a comparison of the results showed good agreement between numerical and experimental results. C.C. Foo et. al. [C.C. Foo, et.al.,2008] made an experimental investigation on aluminum sandwich plates subjected to low-velocity impact. A three-dimensional geometrically correct finite element model of the aluminum honeycomb sandwich plate and a rigid impactor was developed using the commercial software ABAQUS. The results showed that the energy absorbed during impact independent on the core density. Albert U. U. et. al. [Albert U. Ude, et.al., 2010] evaluated the impact energy attenuation and damage characteristics of woven natural silk (WNS)/Epoxy /Honeycomb, WNS/Epoxy/Coremat, WNS/Epoxy/Foam and reinforced WNS/Epoxy (reference sample) laminate panels were subjected to low velocity impact loading, the results showed that WNS/Epoxy/Coremat displayed better load bearing capability qualities compared to the other three samples. Also WNS/Epoxy/Foam was seen as better energy absorber. Paulius G. et. al. [Paulius G., et.al., 2010] carried out experimental investigation of deformation behavior of sandwich structures with honeycomb core in the cases of quasi-static and dynamic loading, According to these results the numerical models were validated and the numerical modeling by finite element method was performed by LS-DYNA v.971 code. The results showed that the dynamical properties of sandwich structure and the deformation behavior depended on the geometry of the sample. Also the honeycomb core absorbs between 50 % and 95 % energy of all sandwich structure. The top face sheet absorbs between 7 % and 35 % and the bottom face sheet absorbs the remnant. N. Baral et. al. [N. Baral, et.al., 2010] developed a test to simulate the water impact (slamming) loading of sandwich boat structures. This test was applied on sandwich panels of Nomex honeycomb cores, Polyimide foam cores, and Pinned foam cores. Their results indicated that the sandwich panels with Pinned foam cores offered significantly improved resistance to wave impact by withstanding higher levels of impact energies. Ramesh S. S. et. al. [Ramesh S. S., et.al., 2011] investigated the low velocity impact response of aluminum honeycomb sandwich panels. The results showed that variation in core height of aluminum honeycomb core does not show any significant change in energy absorbing capacity of the sandwich panels but it increases the time taken to reach peak energy which is desirable for many applications like automobile bumper.

In the present study, impact force and mid span deflection responses of composite sandwich beams with composite honeycomb cores and different face sheets were investigated under low velocity impact tests.

2. Experimental procedure:

2.1. Materials:

Four types of face sheet with the same core were chosen to be investigated. The core was a composite hexagonal honeycomb made of glass fiber and TOPAZ-1110 polyester resin with (7mm) cell width and 20% volume fraction. The face sheets were also made of glass fiber and the same matrix material of core, with 30% volume fraction. The types of the face sheets are as follows:

1- Random fiber mat.
2- Woven fabric mat.
3- Unidirectional fiber with 0^{o} degree orientation.
4- Unidirectional fiber with 90^{o} degree orientation.

The mold consists of two outer glass plates, three plastic plates supporting the glass plates, four plastic longitudinal pieces, and internal hexagonal parts (hexagonal wood bars) that makes the hexagonal honeycomb holes as shown in **fig.1**.

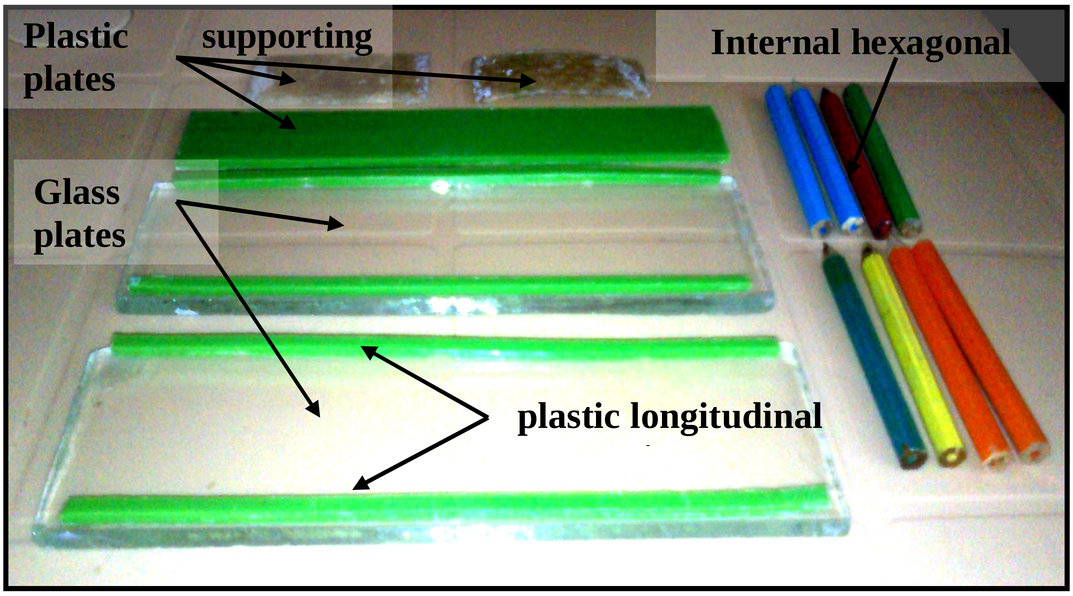

Fig.1 Mold parts.

2.2. Fabrication:

The fabrication process included several sequential steps to get the final structure of test specimens. These are:

1- All parts of mold are covered by layer of insulator plastic film. This insulator plastic prevents sticking of polyester resin to the mold parts.

2- To make the core fiber structure, three random glass fiber mat layers are sewed together at alternate places (first layer to second layer, second layer to third layer, and then first layer to the second layer). This step makes the honeycomb holes. After making every hole, an internal mold part is inserted into this hole.

3- Plastic longitudinal pieces of (3mm) thickness are stuck at the edges of the two glass plates to give the thickness of the face sheets, then, the fiber layers of the face sheets are put on the glass plates with the required setting and orientation between the plastic longitudinal pieces.

4- The first glass plate with the lower face sheet is put on the table, then the core fiber layers with its' internal mold parts is laid on it. Then, the second glass plate with the upper face sheet is laid on the core fiber layers.

5- The two glass plates are fixed and supported by sticking the three plastic plates (two side plates and one lower plate) on it to insure the constancy of overall thickness of the sandwich beam. Then all the gaps between the glass plates and the plastic plates are filled by temperature resistant RTV silicon to prevent leakage of polyester resin. By this step, the total mold is completed.

6- The mold is covered by layers of insulation plastic film and then the polyester resin is poured inside the mold through the two sides. The resin flow through the glass fiber inside the mold from the bottom to the top and fill the space between fibers.

7- The poured resin begins to transform into gelatin phase. In this phase, the internal parts of mold are pulled out. Then the resin begins to solidify.

8- After five hours, the mold is opened and the sandwich beam is bulled out. Then, the molding excrescences are removed by a high speed rotating cutter to get the final shape of the test specimen.

It should be mentioned that in this study, that the face sheets and the core are molded as one piece. So that, the delaminating problem between core and face sheets can be overcomed.

The dimensions of test specimens were 185mm in length, 50mm in width and 18 mm in thickness. The face sheets were 3mm thick and the core was 12mm thick. The final test specimen is shown in the **fig.2**.

Fig.2 The final test specimen

2.3. Quasi-static testing:

Quasi-static tensile and flexular tests were performed to measure the basic mechanical properties of the sandwich beam components (face sheets and core). These tests were done at the mechanical lab. of materials department/ Engineering collage/ Kufa University using (Microcomputer Controlled Electronic Universal Testing Machine, Model WDW-100E).

Tensile test was done according to the ASTM standard (D3039M-00) with constant deformation rate of (2 mm/min).

The flexural was executed test according to the ASTM standard (C393-00) with constant deformation rate of (2 mm/min).

2.4. Low velocity impact tests:

These tests were performed at the post graduated lab. of the mechanical engineering department / Collage of Engineering/ Almustensiriya University by a drop-weight low velocity impact tester which is shown in the **fig.3**. The details of this apparatus are found in [Nawres J. N., 2011]:

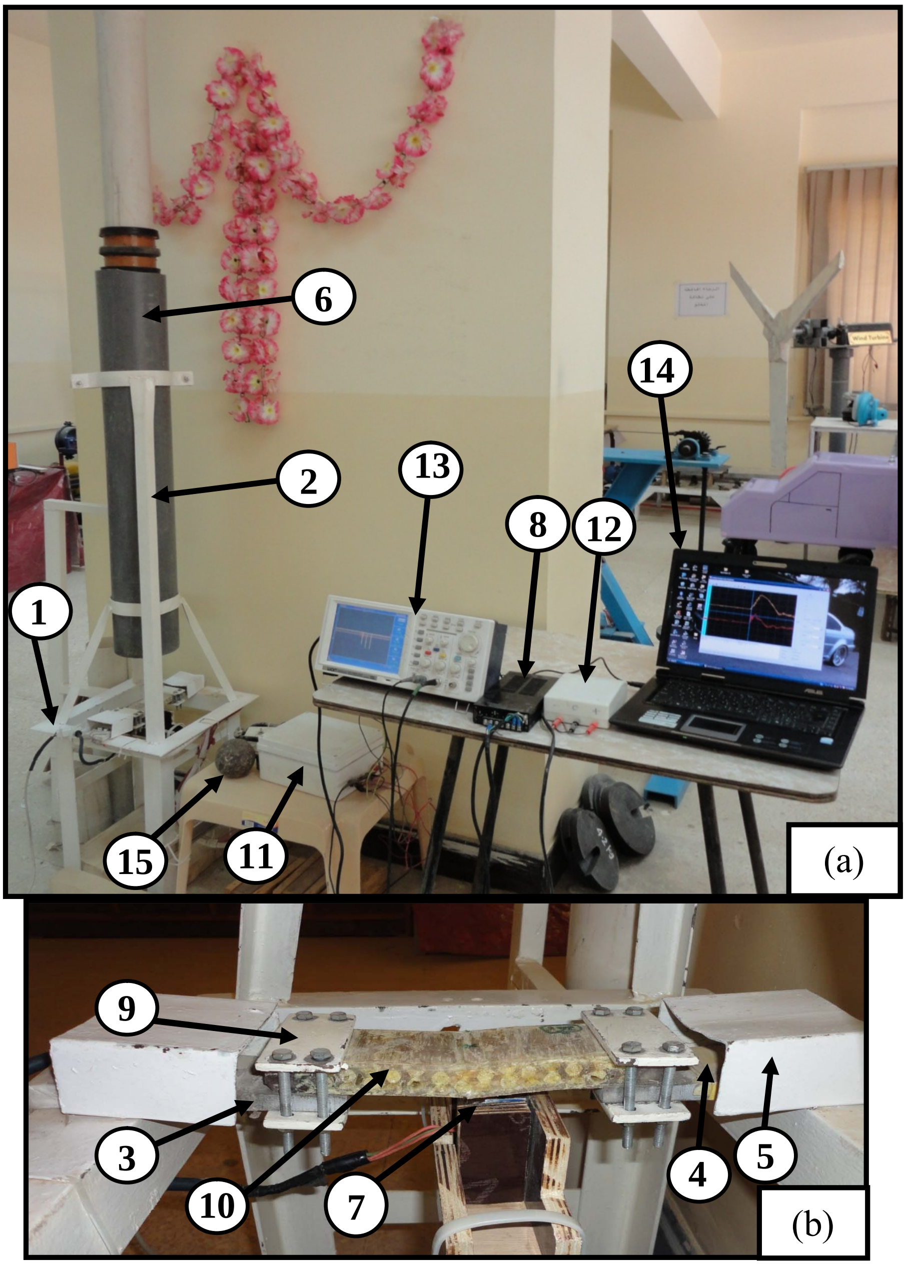

Fig.3 The low velocity impact instrument [Nawres J. N., 2011].

The parts of device are listed below as it is marked in **fig.3**:

1. Base of device., 2. Guide pipe support., 3. Supporting plates., 4. Strain gauges., 5. Strain gauge cover., 6. Dropping guide., 7. Deflection measuring potentiometer., 8. Deflection measuring potentiometer system., 9. Clamps., 10. The specimen., 11. Amplifier and filter., 12. Strain Gage System Power supply., 13. Digital storage oscilloscope., 14. Computer., 15. Impactor.

The test procedure was taken for all specimens. Specimen is clamped to the support plates, then, the measuring systems and oscilloscope are powered on. The oscilloscope is used to read the measured values of impact force and deflection with respect to time and then, it transfer these readings to the computer to be recorded by the program of the oscilloscope. The impactor ball is leaved to drop freely on the test specimen from the required height and the readings are recorded in the same time. Three impact energy values were used (31.22J, 39J, and 43.21J) for every type of sandwich beams. **Table 1** shows the specimens numbers according to type of face sheet:

Table 1 Numbering and types of low velocity impact specimens

Speci. type	Speci. No.	Fiber setting and orientation	Impact energy (J)	Height of drop (m)
1	A	Random fiberglass	31.22	1.25
	B	Random fiberglass	39	1.75
	C	Random fiberglass	43.21	2
2	D	Woven fiberglass	31.22	1.25
	E	Woven fiberglass	39	1.75
	F	Woven fiberglass	43.21	2
3	G	Unidirectional fiberglass 0°	31.22	1.25
	H	Unidirectional fiberglass 0°	39	1.75
	I	Unidirectional fiberglass 0°	43.21	2
4	J	Unidirectional fiberglass 90°	31.22	1.25
	K	Unidirectional fiberglass 90°	39	1.75
	L	Unidirectional fiberglass 90°	43.21	2

3. Results:

3.1. Results of Quasi-static tests:

The obtained results from the tensile tester for all types of face sheet can be represented as a (Stress-Strain) diagram. These results gave the values of the modulus of elasticity (E) for the face sheet types in the direction of loading as shown in **Table 2**:

Table 2 Face sheet modulus of elasticity.

Speci. type	Speci. No.	Modulus of elasticity E (GPa)
1	T1	12.74
2	T2	18.46
3	T3	27.4
4	T4	5.09

Results of the flexural tests gave values of force and deflection. The shear modulus (G) of the hexagonal honeycomb core was calculated according to the analytical procedure of ASTM standard (C393-00), and its value was (0.431177845 GPa).

3.2. Results of Low Velocity Impact Tests:

3.2.1. The force (load) Response:

The force history of each impact event was acquired and the peak force at each impact energy level was obtained as shown in **Figures 4. a, b, c, and d**. It was observed that the peak force increases with increasing of impact energy for all types of specimens, the apparent fluctuation in the force and deflection histories is because of the numerous successive failures in the face sheets and core.

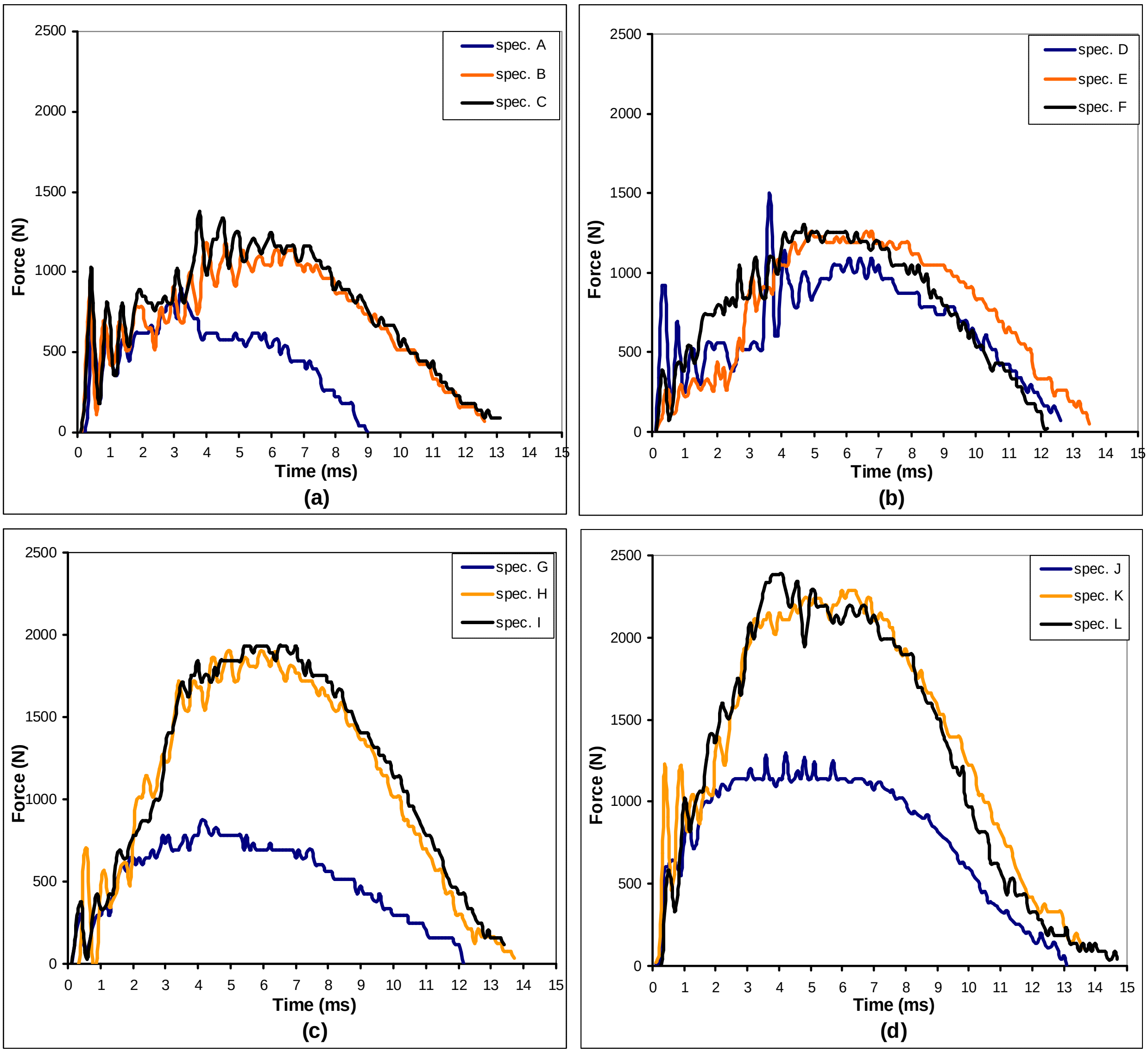

Fig.4 (Force-Time) curves for specimens of: (a) Type (1), (b) Type (2), (c) Type (3), (d) Type (4).

The peak forces of all types of face sheets at impact energy of (31.22J) are approximately close to each other. The peak force at impact energy of (39J) was minimum for the specimen type (1) and maximum for the specimen type (4). For impact energy of (43.21J), the peak force was minimum for the specimen type (2) and maximum for the specimen type (4). These are shown in the comparative **Figures 5 a, b, and c**.

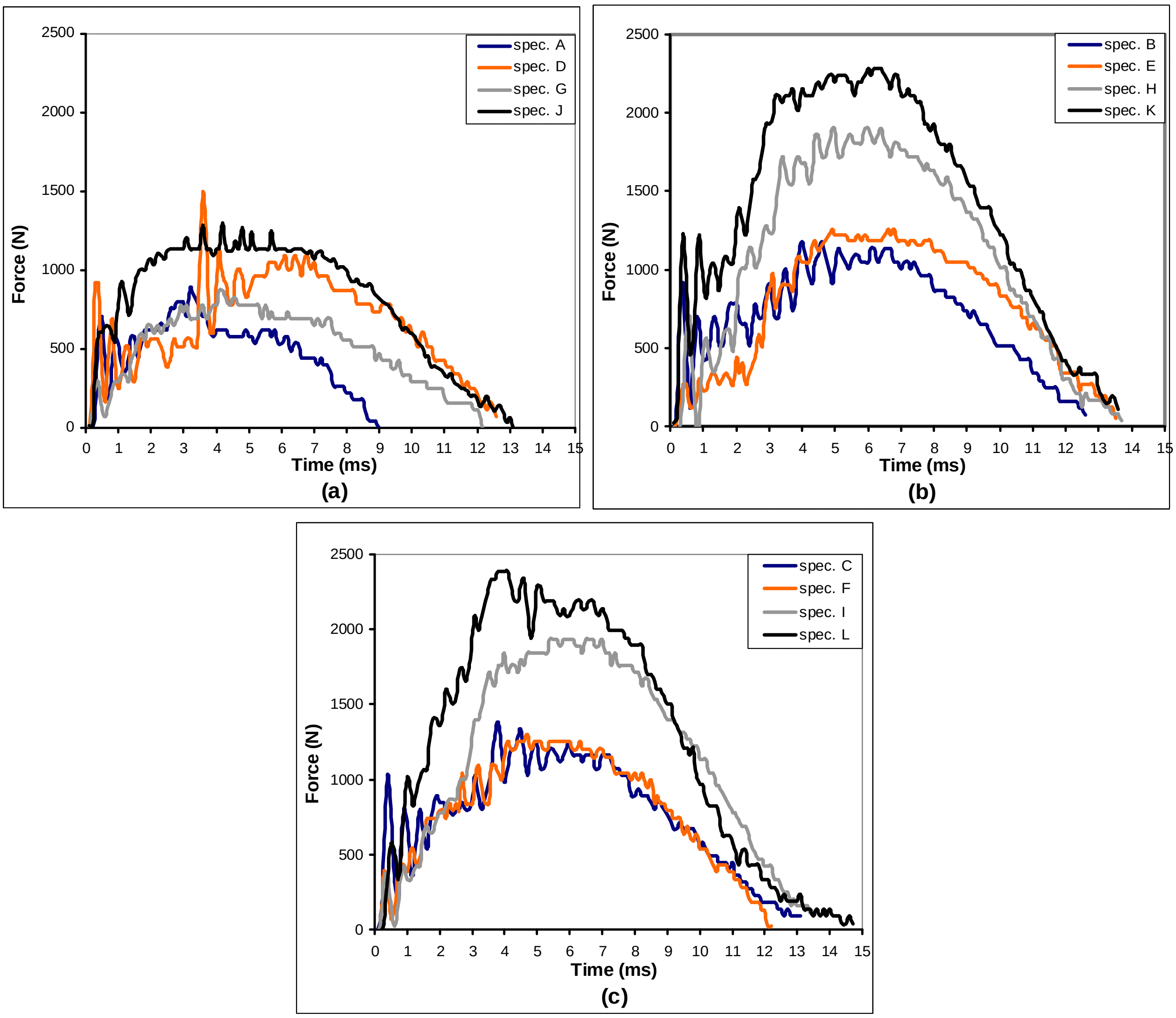

Fig. 5 (Force-Time) curves for (a) Impact energy of (31.22J), (b) Impact energy of (39J), and (c) Impact energy of (43.21J).

At impact energy of (31.22J), the peak force of type (2) increased by (68.13 %) of type (1), the peak force of type (3) decreased by (2.14 %), and the peak force of type (4) increased by (46.17 %). At impact energy of (39J), the peak force of type (2) increased by (6.69 %) of type (1), the peak force of type (3) increased by (60.84 %), and the peak force of type (4) increased by (93.644 %). At impact energy of (43.21J), the peak force of type (2) decreased by (5.79 %) of type (1), the peak force of type (3) increased by (39.971 %), and the peak force of type (4) increased by (72.556%).

3.2.2. The Deflection Response:

Concerning the deflection records, the acquired data are shown in **Figures 6 a, b, c, and d**. Type (1) showed approximately constant maximum deflection for all three applied impact energies. But the other three types showed increasing max. deflection with increasing impact energy.

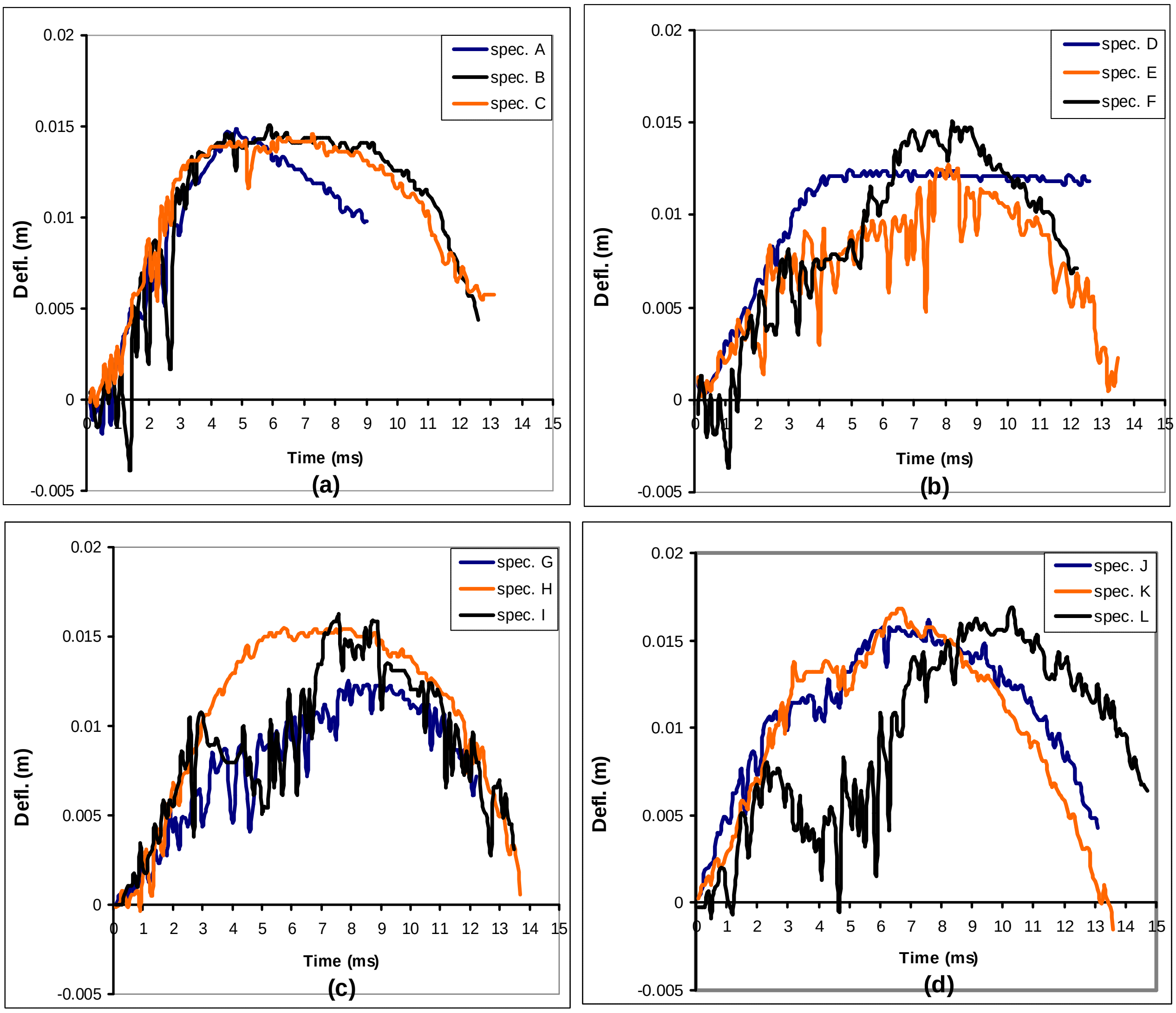

Fig.6 (Defl.-Time) curves for specimens of: (a) Type (1), (b) Type (2), (c) Type (3), (d) Type (4).

A significant drop in deflection followed by re-increasing can be observed at the beginning of the impact event for some types according some values of impact energy. This is observed in the specimen type (3) and type (4) for (43.21J) impact energy. Also this is observed in the specimens type (4) face sheets according to (39J) and (31.22J) impact energies. The mentioned drop in deflection can be ascribed to significant bending failures of specimen face sheets, which represent the biggest deflection percentage of the total impact deflection. All results are shown in **Figures 7a,**

b, and c which describe the deflection responses for all types of specimens according to constant amounts of impact energy.

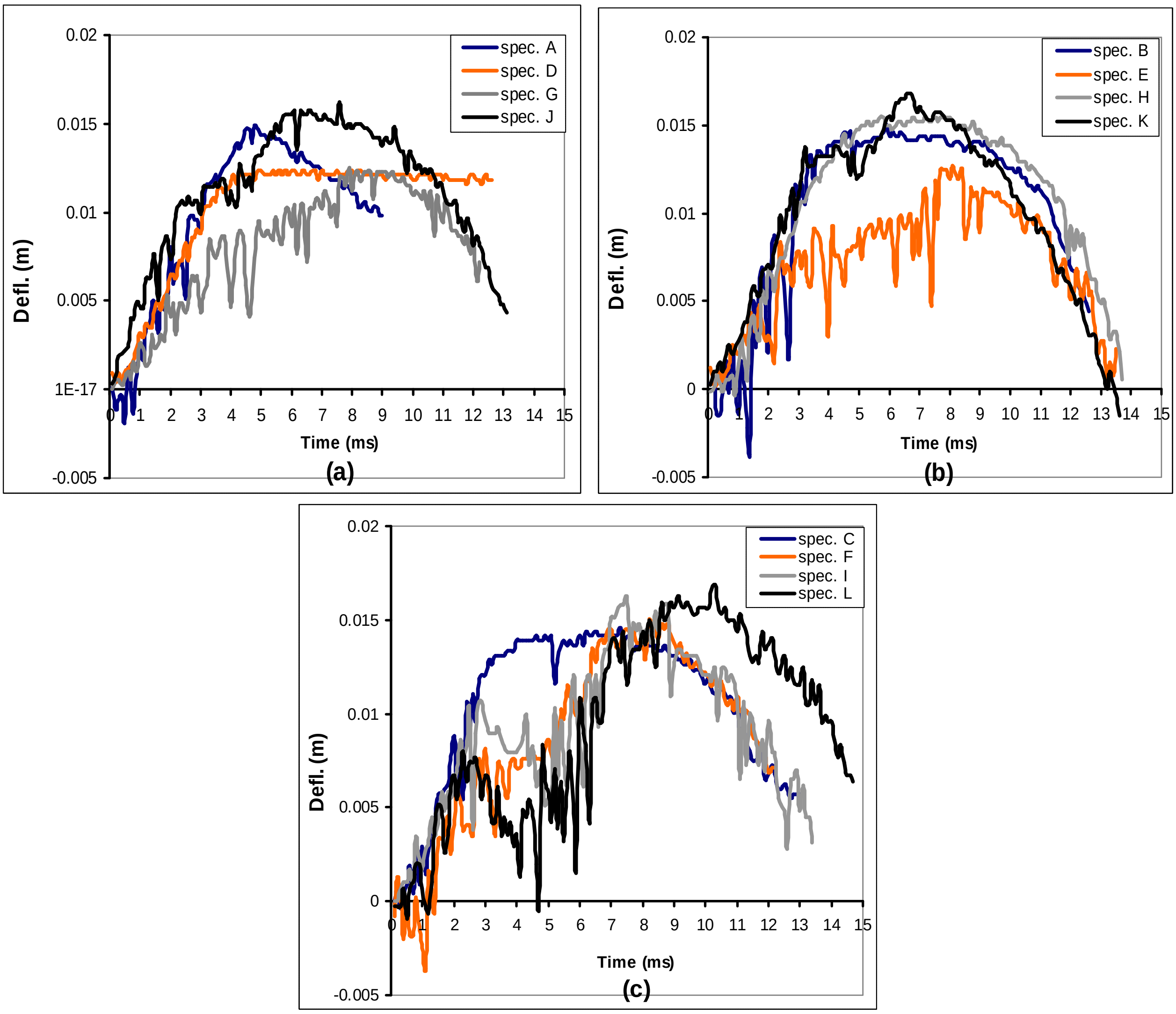

Fig. 7 (Deflection-Time) curves for (a) Impact energy of (31.22J), (b) Impact energy of (39J), and (c) Impact energy of (43.21J).

As in the impact force response, specimen type (1) is taken as a reference in the deflection response. At impact energy of (31.22J), the peak deflection of type (2) decreased by (16.9788 %) of type (1), the peak deflection of type (3) decreased by (16.0578 %), and the peak deflection of type (4) increased by (8.757 %). At impact energy of (39J), the peak deflection of type (2) decreased by (15.83%) of type (1), the peak deflection of type (3) increased by (2.321%), and the peak deflection of type (4) increased by (11.22%). At impact energy of (43.21J), the peak deflection of type (2) increased by (2.953%) of type (1), the peak deflection of type (3) increased by (10.8787%), and the peak deflection of type (4) increased by (15.962%).

3.2.3. Absorbed Energy:

This was calculated according to principle of momentum conservation as in equations (1 and 2) [Paolo Feraboli, 2006]:

$$m(V_2 - V_1) = \int_{t_2}^{t_1} P\,dt \qquad (1)$$

Where:

m= mass of impactor

V_1=0= initial velocity of the impactor at the rebound stage of motion

V_2 = final velocity of the impactor at the rebound stage of motion

t1, t2 = initial and final time of the rebound stage of motion

P = impact force at time (t)

$$E_{ab} = \frac{1}{2} m(V_o^2 - V_2^2) \qquad (2)$$

E_{ab} = Absorbed energy

V_o =initial impact velocity

The values of the absorbed energy for all types of specimens at every value of impact energy are listed in **Table 3** with percentages of the absorbed energy for specimen types (2, 3, and 4) with respect to the specimen type (1) .

Table 3 Absorbed energy of all tested specimens

Spec. No.	Impact energy (J)	Absorbed energy (J)	Percentage of absorbed energy (%)	Percentage of absorbed energy to the absorbed energy of type (1) (%)
A	31.22	29.8174924	95.50766	-
B	39	35.97525	92.24423	-
C	43.21	38.9389027	90.11549	-
D	31.22	27.6459064	88.55191	92.717
E	39	32.5353635	83.42401	90.438
F	43.21	37.3968056	86.546646	96.0397
G	31.22	28.3173136	90.702478	94.97
H	39	26.8166006	68.760514	74.5747
I	43.21	25.7780249	59.657544	66.2
J	31.22	21.6717991	69.416397	72.681
K	39	14.5804262	37.385708	40.52
L	43.21	21.9113418	50.70896	56.27

It observed in **Table 3** that the percentage of absorbed energy to the impact energy decreased with the increase in impact energy in all types. The absorbed energy was maximum in the type (1) and was minimum in the type (4). The type (1) have the best drop in absorbed energy with respect to the impact energy.

4. Conclusions:

The main conclusions are as follows:

1. There is significant difference in the response of the different types of sandwich beams concerning peak force, peak deflection, and absorbed energy according to the applied impact energies and the face sheet type.
2. The type (4) with unidirectional fiber (90°) face sheets, showed the maximum peak forces for the applied impact energies, while the type (1) with random fiber face sheets had the minimum peak forces. The peak deflection of all types were convergent to each other and they were analogous.
3. It is observed that increasing of impact energy led to maximum increase in peak force for the type (4), since there was significant difference in peak force for the three values of impact energy. This manner was minimum in the type (2); since there was small difference between peak forces of the different applied impact energies.
4. Absorbed energy was maximum in the type (1) and was minimum in the type (4). The percentage of absorbed energy to the impact energy decreased with the increase in impact energy in all types but it was significant in the type (4), which showed the worst drop in percentage of absorbed energy. On the other hand, the type (1) showed minimum drop and maximum stability of absorbed energy percentage.

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