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Investigation of low velocity impact behaviors of honeycomb sandwich composites †

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Abstract

Honeycomb sandwich composites are used as significant structural members in advanced engineering applications. Thus, it is critical to determine how they behave under impact loading, in addition to other loads. In this study, low velocity impact loading behaviors of honeycomb sandwich composites were experimentally investigated. Almost all of the design parameters of honeycomb sandwich composites were investigated. The results indicated that the core thickness of honeycomb had no effect on the strength of the composite, and the parameter influencing the impact behavior of the specimen the most was the face sheet thickness. When the face sheet thickness of the specimen was increased, the most apparent strength increase was observed in the models using carbon fiber-reinforced composite face sheets. For all face sheet types subject to impact energy of 10 Joules, the upper face sheets of 0.5 mm-thick specimens were perforated.

Keywords: Honeycomb sandwich composites; Low velocity impact; CFRP

1. Introduction

Composite materials are one of the fundamental materials used in today's engineering applications. They are popular because they offer significant advantages, like high strength and low weight. Composite materials are usually obtained by combining two or more materials. They consist of fibers and a matrix material that holds the fibers together. Composite materials can be adapted for various applications. Sandwich composites are particularly preferred for low weight applications.

Honeycomb sandwich materials have a wide range of uses in aerospace and transportation applications thanks to their high specific strength and high rigidity values. As a result of developing technologies and the high usage of honeycomb composites, many researchers have studied them to determine and develop the mechanical properties of honeycomb composites.

Honeycomb cores can be produced from various materials, such as aluminum, Nomex™ and polypropylene. Where the sandwich structure will be used and the loads that it will be subject to, directly affect the material choice [1].

Honeycomb sandwich composites increase the moment of inertia due to the honeycomb core and provide rigidity, especially against bending loads [2]. Increasing the face sheet thickness of the selected core material provides more bending stiffness but reduces the buckling resistance [3]. Foam filled sandwich structures gained attention due to their excellent energy absorption capacity [4].

Herup et al. applied sandwich composite materials, which were made of Nomex™ honeycomb cores and graphite/epoxy face sheets having between 4 to 48 laminates, to low velocity impact and static indentation tests. The effects of the loading rate and face sheet material on the strength of the composite were investigated in the study. It was observed that the results of static indentation and low velocity impact test results were similar. The damage load in static indentation tests was found to be lower than that in low velocity impact tests. The increase in the thickness of the face sheet material also increased the difference between the two tests [5].

Tan and Akil used fiber-metal laminates as skin and polypropylene honeycomb as the core. Impact behaviors of the composites were determined by low velocity impact tests. Impact force and time were recorded and then analyzed. It was seen that increasing impact energy increased the contact force. Images obtained from impact testing showed that increased impact energy changed the damage area. When the impact energy was between 7.84 Joules and 11.76 Joules, delamination in the skins and bending in the sandwich structure was observed [6].

Akatay et al. experimentally investigated the repeated low velocity impact behavior of 10 mm-thick sandwich compos-

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ites with honeycomb cells made from Al 5052 alloy. In the study, the Gillfloor™ 5424 Type II model composite, which is preferred for the passenger floors of Boeing 737-800 aircraft, was used. The tests were carried out on the Dynatup 9250 HV model test machine. Samples of 100 mm × 100 mm were cut from a 1219 mm × 3658 mm panel. The thicknesses of the honeycomb and face sheet were 9.086 mm and 0.45 mm, respectively. Tests were conducted for impact energy values of 3, 5, 8, 10, 20, 30, 40, 45, 50, 60, 70, 80, 90, 100 and 110 Joules. The results showed that the energy value of 110 Joules perforated the sample at the first impact. As the collision energy fell, a greater number of collisions were required to perforate the specimen. The maximum number of collisions for damage was found to be 81 collisions for 3 Joules of impact energy [7].

Schubel et al. subjected the specimens produced to impact tests with a falling mass using a woven, carbon fiber composite and a PVC-foam core. Delamination and permanent indentation were observed on the face sheets where the impact load was applied. Impacted samples were then subjected to compression tests, and the results were compared to those of undamaged samples. Although it was difficult to visually determine, it was found that delamination damage significantly reduced the load-carrying capacity of the specimen [8].

Galehdari et al. analyzed the low velocity impact and quasi-static behaviors of reinforced, honeycomb sandwich composites. A plateau stress calculation was performed analytically using the lower-bound theorem. The analytical study was compared with tests using aluminum 6061 specimens. Uniaxial tensile tests were carried out to determine the material properties. Low velocity impact and static tests were done using a drop weight and Santam compression machines. Experimental studies were simulated by the Abaqus software program. The results showed that there was an agreement between experimental, analytical and numerical studies. Damage was usually seen in the form of a "V" [9].

Baba (2017) experimentally investigated the behaviors and damage types of curved sandwich composites with a foam core under impact energy. Three different foam types were used in the study as the core material, including six combinations. Contact force, deformation and full perforation energies of square specimens were determined, and the types of damage were investigated. The results showed that full perforation of the sandwich composites was dependent on geometric parameters and material properties. It was observed that full perforation energy was higher in curved models than in flat models. In fully perforated specimens different core structure variations changed the damage type. It was determined that different core arrangements are necessary for the curved sandwich composites to be used in different application areas [10].

In this study, the impact behaviors of honeycomb sandwich composites under low velocity tests were investigated. Honeycomb sandwich composites were produced by varying the type and thickness of the face-sheet material, and the honeycomb cell size and thickness. Low-velocity impact loading tests were performed using CEAST-Fractovis Plus Impact Test Equipment.

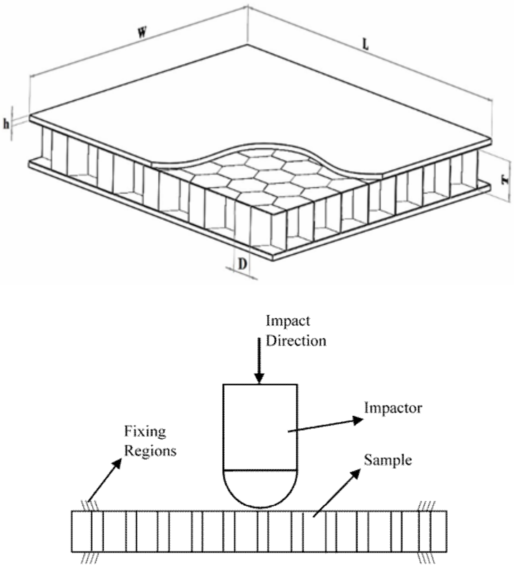


Fig. 1. Sample dimensions and loading conditions.

2. Experimental part

In this study, low velocity impact behaviors of honeycomb sandwich composites were experimentally investigated.

The honeycomb cells used in the study were made of AL-3003 alloy. They were placed between two face sheets manufactured from AL-5754 alloy, and glass fiber-reinforced composite and carbon fiber-reinforced composite plates, respectively. The adhesion between the face sheets and honeycomb cells was provided by an epoxy-based adhesive (3M 2216).

The honeycomb cells had a cell size of 6.35 mm and three different core thicknesses: 10 mm, 15 mm and 20 mm. The thicknesses of face sheet materials were 0.5 mm, 1 mm and 1.5 mm. The specimens produced were 80 mm wide and 135 mm long. Sample dimensions and loading conditions are given in Fig. 1.

In naming the specimens, the first number of the specimen label is used to identify the cell size. For example, the number 6 defines a 6.35 mm size cell. The letter sequence in the second line defines the type of face sheet material. The abbreviations used are AL: Aluminum, CFRP: Carbon fiber-reinforced composite and GFRP: Glass fiber-reinforced composite, respectively. The third number in the line defines the core thickness value, which is 10, 15 or 20 mm, respectively, and the last in the sequence (a, b and c) defines the thickness of the face sheet material. The thicknesses are 0.5 mm, 1 mm and 1.5 mm, respectively. To illustrate this labeling, the "6AL10b" label defines the specimen as having a 6 mm size cell, an aluminum face sheet, a 10 mm core thickness and a 1 mm face sheet thickness.

Table 1. Mechanical properties of fiber reinforced composites.

	E_1 (GPa)	E_2 (GPa)	ν_{12}	G_{12} (GPa)
CFRP	83.4	83.5	0.05	6.8
GFRP	44.15	12.3	0.2	4.096

2.1 Preparation of specimens

The face sheet materials were ground using 180 sandpaper. In accordance with the data sheet of 3M 2216 adhesive, the aluminum materials were cleaned with acetone and the composite materials were cleaned with isopropyl alcohol.

Jen et al. indicated that a 0.7 kg/m^2 amount of adhesive provided maximum strength [11]. Therefore, 7.5 g of adhesive, which is equal to 0.7 kg/m^2, was applied to the cleaned surfaces with a spatula. The specimens were put under 2.5 kg concrete weights to ensure the same pressure on all specimens.

Another face of the specimen was bonded after 1 day of curing. To achieve a complete curing of the adhesive, the sandwich composites were left at room temperature for one week before the tests were carried out.

2.2 Mechanical properties of materials

The mechanical properties of materials used in the study were determined by using Shimadzu Universal test equipment, which has two different load cells (5 kN and 250 kN) to carry out quasi-static tests with.

After the tests were conducted, the elastic modulus and Poisson ratio of the 3M 2216 adhesive was found to be 565 MPa and 0.47, respectively, while the elastic modulus and Poisson ratio of aluminum was 70.3 GPa and 0.33, respectively.

The mechanical properties of glass fiber- and carbon fiber-reinforced composites are shown in Table 1.

Impact tests were conducted using CEAST-fractovis plus impact test equipment. In tests, a 5120 g hemisphere steel impactor with a diameter of 12.7 mm was used. Tests were carried out for collision energies of 5 Joules and 10 Joules. The lower and upper supports used to hold the specimen during the impact were 76 mm in diameter. The test equipment has an 1800 Joule energy capacity and a 22 kN load cell. There is an anti-rebounding system for prevent successive impacts. The test equipment used in the tests is shown in Fig. 2.

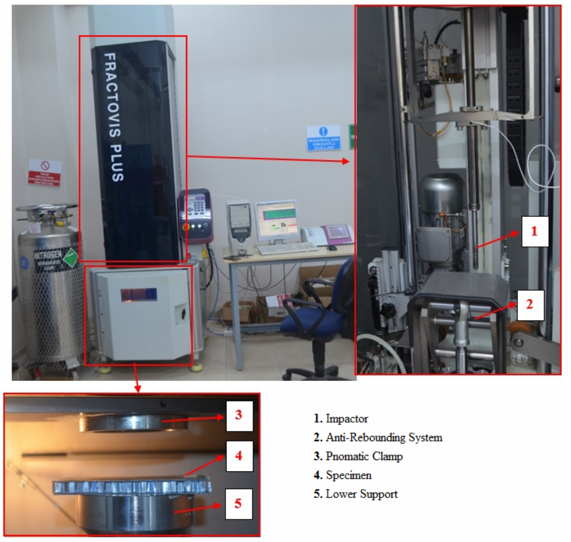
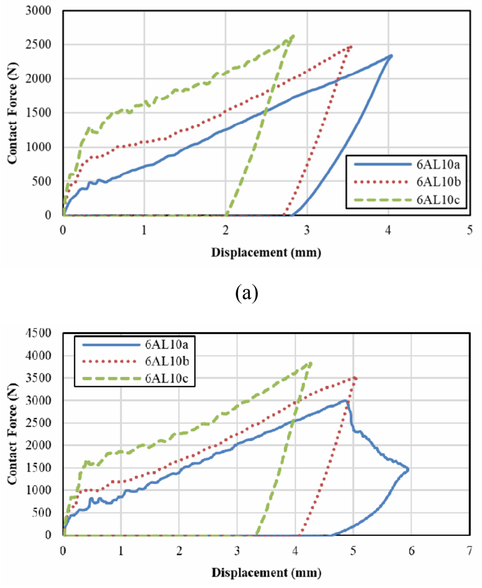


Fig. 2. CEAST-fractovis plus impact test equipment.

3. Results and discussion

Impact tests were performed using a 12.7 mm diameter impactor. The specimens were placed between pneumatically operated supports, and tests were done for different impact energies. In evaluating the graphs obtained from the impact tests, it is possible to determine the amount of energy absorbed by the specimen, the amount of return energy, and whether the impactor perforated the specimen.

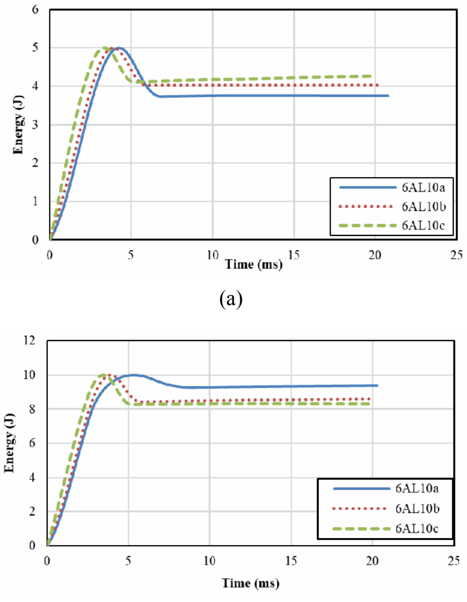


(a)

(b)

Fig. 3. The effect of aluminum face sheet thickness on the contact force: (a) 5 J; (b) 10 J.

The effect of aluminium face sheet thickness on the contact force is shown in Fig. 3. For both energy values, an increase in the face sheet thickness also increased the contact force. For 5 Joules of impact energy, the contact forces were 2338.575 N, 2471.803 N and 2624.873 N for face sheet thicknesses of 0.5, 1 and 1.5 mm, respectively. The contact forces for 10 Joules of impact energy were higher than those for 5 Joules of impact energy and were measured to be 2993.376 N, 3526.287 N and 3838.097 N for face sheet thicknesses of 0.5, 1 and 1.5 mm, respectively. As a result of the tests, only the model with a face sheet thickness of 0.5 mm was perforated at the 10 Joule energy value. The impactor perforated the upper face sheet and stuck to the specimen.



(a)

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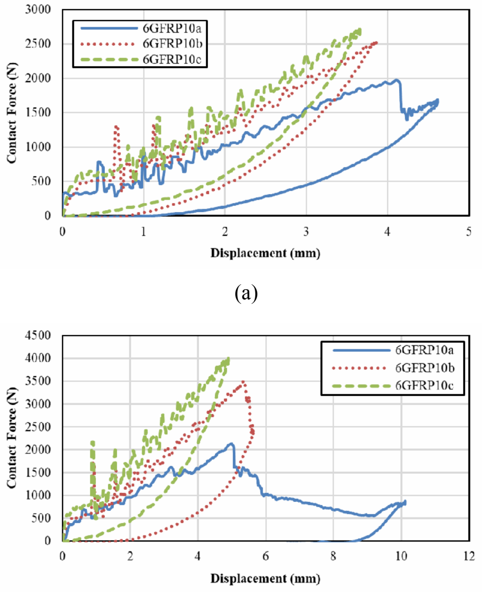
Fig. 4. The effect of aluminium face sheet thickness on the energy behavior: (a) 5 J; (b) 10 J.

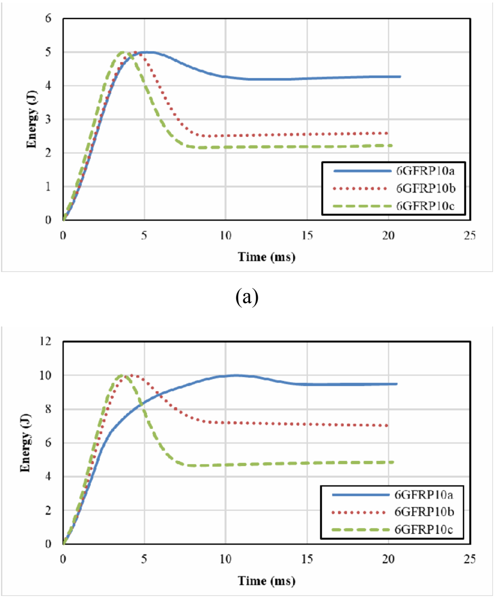


(a)

(b)

Fig. 5. The Effect of GFRP face sheet thickness on the contact force: (a) 5 J; (b) 10 J.

The effect that the thickness of the aluminum face sheet had on the energy behavior of composites is shown in Fig. 4. Considering the absorbed energy values, increasing the face sheet thickness increased the amount of absorbed energy for 5 Joules of impact energy. However, for 10 Joules of impact energy, increasing the face sheet thickness decreased the amount of absorbed energy. For 10 Joules of impact energy, the amount of energy absorbed by the specimen with a 0.5 mm face sheet thickness was found to be 9.344 Joules. The reason that the absorbed energy was very close to the impact energy was because the impactor perforated the upper face sheet of the composite and stuck to it.



(a)

(b)

Fig. 6. The effect of GFRP face sheet thickness on the energy behavior: (a) 5 J; (b) 10 J.

In specimens with aluminum face sheets there was no apparent effect observed when the core thickness was changed according to the Energy-Time graph. This result is compatible with other studies in published literature [12-15].

The effect of the face sheet thickness of glass fiber-reinforced composite on the contact force is shown in Fig. 5. The graphs showed a more alternating tendency compared to the models with aluminum face sheets. The fracture of glass fibers during impact testing and sudden strength decreases are possible reasons for this result.

For 5 Joules of impact energy, the maximum contact force of the specimen with a 0.5 mm-thick face sheet was found to be 1975.74 N, while increasing the face sheet thickness to 1 mm increased the contact force to 255.68 N, which corresponds to a 30 % increase. When the face sheet thickness was increased to 1.5 mm, the contact forced increased to 2712.75 N, which was 6 % higher than the specimen with the 1 mm-thick face sheet.

For 10 Joules of impact energy, the maximum contact forces were found to be 2128.81 N, 3492.27 N and 3999.67 N for the 0.5, 1 and 1.5 mm face sheet thickness values, respectively.

The effect of the face sheet thickness of glass fiber-reinforced composites on the energy behavior of composites is shown in Fig. 6. For both energy values, increasing the face sheet thickness decreased the amount of absorbed energy. The upper face sheet of the 6GFRP10a specimen, which absorbed 95 % of the overall energy, was substantially perforated, and the highest core damage was observed in this specimen.

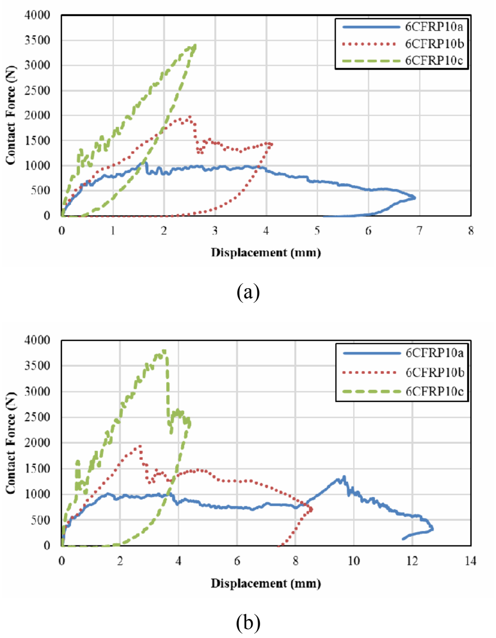


Fig. 7. The effect of CFRP face sheet thickness on the contact force: (a) 5 J; (b) 10 J.

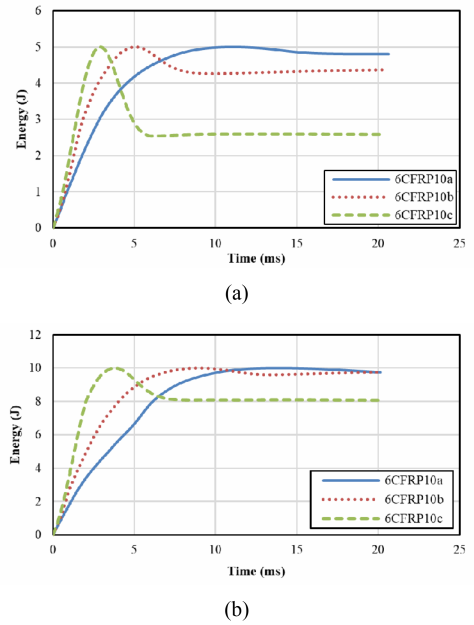


Fig. 8. The effect of CFRP face sheet thickness on the energy behavior: (a) 5 J; (b) 10 J.

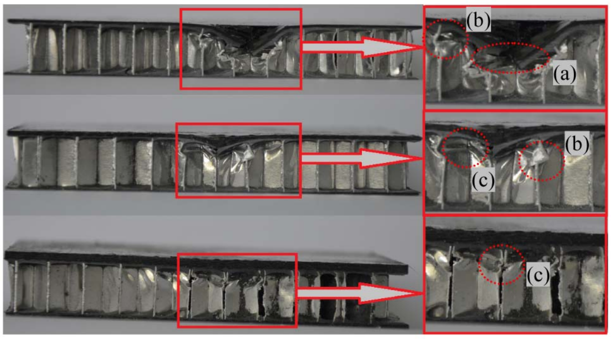


Fig. 9. Impacted specimens with carbon fiber face sheet: (a) Face sheet failure; (b) tear of cell wall; (c) cell wall buckling failure.

For 0.5 mm and 1 mm face sheet thickness values, the debonding region that reveals the damage diameter caused by the impactor is larger for 5 Joules of impact energy than it is for 10 Joules of impact energy. However, when the depth of damage occurring on the face sheet is measured, it was observed that increased impact energy caused more deformation. In specimens with a 1.5 mm face sheet thickness, the reason for the increase in the debonding region is that the delamination observed between the core and face sheet—due to an increase in the rigidity of the face sheet—is the basic damage type.

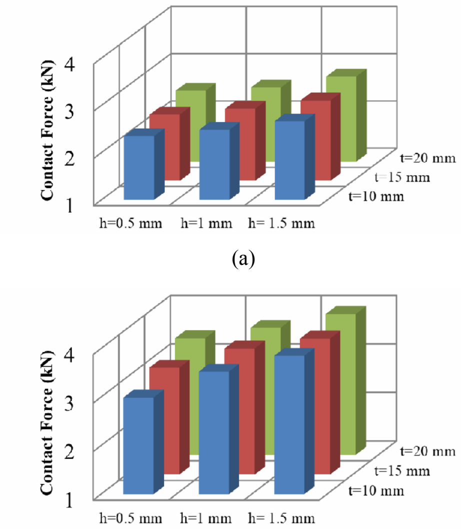
Contact force - displacement curves observed in the specimens with carbon fiber-reinforced composite face sheets are shown in Fig. 7. The upper face sheets of the specimens with 0.5 mm thicknesses were perforated at both energy values, while 10 Joules of impact energy caused perforation of both face sheets. Increasing the face sheet thickness increased the contact force for both energy values. The highest contact force (3801.25 N) was observed in the specimen with a 1.5 mm face sheet thickness under 10 Joules of impact energy. On the other hand, the lowest contact force (1074.32 N) was seen in the specimen with an 0.5 mm face sheet thickness under 5 Joules of impact energy.

The effect of the face sheet thickness of carbon fiber-reinforced composite on the impact energy behavior of composites is shown in Fig. 8. The 6CFRP10c specimen with a 1.5 mm face sheet thickness absorbed energy of 2.591 Joules under 5 Joules of impact energy, and energy of 8.084 Joules under 10 Joules of impact energy, making it the highest energy absorbing one among all the specimens. For 10 Joules of impact energy, the specimen with a 0.5 mm face sheet thickness absorbed all its energy while the specimen with a 1 mm face sheet thickness absorbed energy of 9.609 Joules.

The images of the specimens with carbon fiber-reinforced composite face sheets—obtained after the 5 Joule impact energy tests—are shown in Fig. 9. Examining the figure, it can be seen that the upper face sheet of the 6CFRP10a and 6CFRP10b specimens were perforated at 5 J energy value. In 6CFRP10c specimen where a partial perforation was seen, regional fiber and delamination damage was also seen [6].

The change of contact force with impact energy, face sheet thickness and core thickness in the specimens with aluminum face sheets, is shown in Fig. 10. As seen in this figure, for both energy values, an increase in the face sheet and core thickness values increased the maximum contact force. The effect of face sheet thickness on the contact force is more pronounced than that of core thickness, and 10 Joules of impact energy resulted in higher contact forces.

For all face sheet materials, increasing the face sheet thick-



(a)

(b)

Fig. 10. The change of contact forces with the impact energy for different core and face sheet thicknesses: (a) 5 J; (b) 10 J.

ness increased the maximum contact force. Furthermore, changing the face sheet thickness mainly affected the specimens with carbon fiber-reinforced composite. The highest contact force was observed in the specimen with a carbon fiber-reinforced composite face sheet and 5 Joules of impact energy, while it was seen in the specimen with a glass fiber-reinforced composite face sheet for 10 Joules of impact energy. For the lowest face sheet thickness (0.5 mm), the highest contact forces were found in the specimens with aluminum face sheets for both energy values.

4. Conclusions

In this study, the impact behaviors of honeycomb sandwich composites under low velocity tests were investigated. The results obtained from the tests are given below:

- Increasing the face sheet thickness of honeycomb composites increased the impact strength values of the specimens for all types of face sheet materials.
- Changing the face sheet thickness mainly influenced the specimens with carbon fiber-reinforced composite face sheets. When the face sheet thickness increased, the strengths of the specimens with carbon fiber-reinforced composite face sheets substantially increased.
- Increasing the core thickness of honeycomb did not change the absorbed energy and damage diameter; however, the damage depth increased with increasing core thickness.
- For 10 Joules of impact energy, the upper face sheet was perforated in the specimens with a 0.5 mm face sheet thickness. All of the impact energy was absorbed by the specimens because the impactor stuck in the specimen.
- In the tests carried out using 10 Joules of impact energy, in addition to the perforation of the upper face sheet, the lower face sheet of the specimen - with a 0.5 mm-thick carbon fiber-reinforced composite - was also perforated.

Acknowledgments

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