Flexural and Compressive Behaviour of M-shaped Core Sandwich Panel with Hybrid Carbon-Glass Fiber

Himan Khaledi[1*]

Abstract–In the present research, the flexural and compressive behaviour of foam-filled sandwich panels M-shaped core with hybrid carbon-glass fiber composite has been experimentally investigated. In order to fabricate the sandwich panels, the vacuum-assisted resin transfer molding (VARTM) has been used to achieve a laminate without any fault. Afterward, polyurethane foam with density of 80 Kg/m3 has been injected into the core of the sandwich panel. The flexural and compressive properties of sandwich panel with hybrid carbon-glass fiber [CGCG]s have been compared to those of eight-layered carbon fiber [C]8 and the eight-layered glass fiber [G]8. The study of force-displacement curves obtained from the compressive and three-point bending tests showed that the [CGCG]shave a larger elastic region than [C]8 and a larger plastic region than [G]8. Also, it was found that polyurethane foam enhanced the ultimate compressive and bending loads and absorber features of sandwich panels.

Keywords: Sandwich panel; hybrid; Flexural behaviour; Compressive behaviour; polyurethane foam

1. Introduction

Light-weight structures are one of the most important issues in the transportation industry that greatly affects fuel consumption, while glass fiber composites have been used extensively to replace steel in the transportation sector, but still composite Carbon fiber fibers have a special place due to their lower weight and higher hardness along with greater strength than glass fiber composite. However, due to its high cost compared to composite glass fibers, it has a more limited consumption. Therefore, for more weight loss and higher strength in the transportation industry, without over-increasing costs, hybridization of carbon and glass fibers with different percentages of hybridization can be used. Many researchers have been performed on the mechanical behaviour of the hybrid composite sandwich panels.

Jetshi et al. [1] determined enhancement of mechanical and specific wear properties of glass/carbon fiber reinforced polymer hybrid composite. Their results revealed that the flexural strength and tensile strain are improved through hybridization. Zhang et al. [2] studied the glass-carbon fiber hybrid composite laminates for structural applications in automotive vehicles. They showed that hybrid composite laminates with 50 % carbon fibre reinforcement provide the best flexural properties when the carbon layers are at the exterior, while the alternating carbon-glass lay-up provides the highest compressive strength. Rajpurohit et al. [3] considered the hybrid effect in in-plane loading of carbon-glass fibre based inter and interplay hybrid composites. The results showed that different hybridization strategies can be exploited to balance the cost and performance of composites for structural and lightweight applications. Singh and Chawla [4] considered the hybrid effect of functionally graded hybrid composites of glass–carbon fibers. They made hybrid composite having linear gradation of carbon and glass fibers and compared its material properties with classical sandwich hybrid laminates, i.e., carbon fibers in between glass fibers or vice versa. Impact behaviour and post-impact compressive characteristics of glass–carbon/epoxy hybrid

composites with alternate stacking sequences were investigated by Naik et al. [5]. Subagia et al. [6] determined the effect of stacking sequence on the flexural properties of hybrid composites reinforced with carbon and basalt fibers. Their results showed that the flexural strength and modulus of hybrid composite laminates were strongly dependent

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[1*] **Corresponding Author**: Department of Mechanical Engineering, Sari Branch, Islamic Azad University, Sari, Iran.

Email: himankhaledi@yahoo.com

Received: 2022.08.07; Accepted: 2022.08.23

on the sequence of fiber reinforcement. Djama et al. [7] investigated the mechanical behaviour of a sandwich panel composed of hybrid skins and novel glass fiber reinforced polymer truss core. In their study, the compressive and shear-specific strengths of the panels were assessed and compared with a few common lightweight structures to verify that the manufactured truss core had comparable values. Djama [8] used hybrid sandwich panels for building purpose by focus on glass fibre reinforced polymer and mineral matrix interface. The Bending behaviour of sandwich structures with different fiber facing types and extremely low-density foam cores have been investigated by Uzay et al. [9]. A study on the bending response of a composite curved panel with pyramidal metallic truss cores suitable for functional applications by using a combination of analytical modeling, three-point bending experiments and finite element based simulations. was presented by Xiong et al. [10]. Hosur et al. [11] experimentally determined the response of four different combinations of hybrid laminates to low-velocity impact loading using an instrumented impact testing machine. Sarasini et al. [12] studied the effects of basalt fiber hybridization on quasi-static mechanical

properties and low velocity impact behaviour of carbon/epoxy laminates. Their Results indicated that hybrid laminates with intercalated configuration have better impact energy absorption capability and enhanced damage tolerance with respect to the all-carbon laminates, while hybrid laminates with sandwich-like configuration presented the most favorable flexural behaviour. Sayahlatifi et al. [13] numerically and experimentally studied the quasi-static behaviour of hybrid corrugated composite/balsa core sandwich structures in four-point bending. The parametric study showed that with increasing the corrugation angle and thickness, the specific strength/stiffness exhibited an ascending trend. Moreover, rectangular-shaped corrugation contributed to the best mechanical performance. Florence et al. [14] studied the effect of energy-absorbing materials on the mechanical behaviour of hybrid fiber-reinforced plastic honeycomb core sandwich composites which were under the three-point bending, edgewise compression, flatwise compression and Charpy impact. Rupp et al. [15] focused on failure mode maps of hybrid sandwich panels under bending load, which have been produced using a polyurethane spraying process. Kim et al. [16] designed, optimized and fabricated of hybrid glass/carbon fiber reinforced composite bumper beam for automobile vehicles. Based on their results, it was found that the optimally designed glass/carbon mat thermoplastic bumper beam had 33% less weight compared to the conventional glass mat thermoplastic bumper beam while having improved impact performances. Mechanical properties of hybrid Glass/Carbon fiber reinforced epoxy composites have been determined by Bhagwat et al. [17]. Hoffman et al. [18] determined the effect of a surface coating on the flexural performance of thermally aged hybrid glass/carbon epoxy composite rods. Based on their results, it was found that the uncoated rods lost significantly more flexural stiffness and strength than the coated rods. Naresh et al. [19] investigated the effect of high strain rate on glass/carbon/hybrid fiber reinforced epoxy laminated composites. Their results indicated that the tensile strength and tensile modulus of GFRP and hybrid composites increase and percentage of failure strain for glass fiber reinforced plastic (GFRP), carbon fiber reinforced plastic (GFRP) and Hybrid composites decreases with the increase in strain rate, whereas tensile strength and tensile modulus of CFRP composites remains approximately constant. Marston et al. [20] investigated the effect of fiber sizing on fibers and bundle strength in hybrid glass carbon fiber composites. They showed that the strength of the impregnated tows in hybrid composites was seen to be 15% higher than those tested in air.

In general, the purpose of hybridizing of two fibers in a composite is to obtain the advantages of two fibers and reduce their disadvantages. By replacing ductile fibers with brittle fibers in a polymer-based composite, the strain of failure can be improved.

According to the above explanations, the aim of this study is to hybridize carbon fibers and glass fibers in polymer substrate and investigate the hybrid properties under tensile, three-point bending, and compressive loads. In addition, the influence of polyurethane foam on the mechanical behaviour of the sandwich panel under the mechanical tests is investigated.

2. Materials description

In this research, in order to manufacture the sandwich panel with hybrid carbon-glass fiber, two-directional fibre glass (E-type) with the mass of 200 gram, two-directional carbon fibers (T300), and epoxy resin EC 130 LV for matrix phase have been used which their properties are shown in Table 1 and 2. Also, the material properties of polyurethane foam have been presented in Table 3.

Table 1. Material properties of Two-directional carbon and glass fiber

	Elongation (%)	Tensile modulus (GPa)	Tensile strength (MPa)	Density (g/cm^3)
Carbon fiber (T300)	1.5	230	3500	1.76
Glass fiber (E-type)	2.5	72	3400	2.5

Table 2. Resin epoxy properties

Commercial name	EC 130 LV (Resin)	W340 (Hardener)
Viscosity at 25℃ (mPa.s)	1200-1600	45-55
Initial mixture viscosity at 25℃ (mPa.s)	500-800	-
Pot life at 25℃ (min)	95-117	-
Density at 25℃ (g/ml)	1.14-1.16	0.92-0.94

Table 3. Material properties of polyurethane foam

Elongation (%)	Young’s modulus (MPa)	Yield stress (MPa)	Density (Kg/m^3)
1.5	24	1.41	80

3. Laminates production

In this study, composite laminates include eight layers that are layered in three different arrangements. The first one is eight-layered carbon fiber [C]8 and the second one is eight-layered glass fiber [G]8 and, finally, the third one is hybrid carbon-glass fiber [CGCG]s where C is symbol of carbon and G is a symbol of glass. The symbol 8[C] means a laminate consisting of 8 layers of bidirectional carbon fibers, and S [CGCG] means a laminate with 4 layers of carbon fibers and 4 layers of glass fibers as one, and also 8[G] It means a ceiling consisting of 8 layers of glass fibers The type of layer arrangement is shown in figure 1. Also, the schematic view of all three types of composites, which were introduced above, has been shown in Figure 2.

Fig.1. [CGCG]s arrangement for FRP hybrid composite

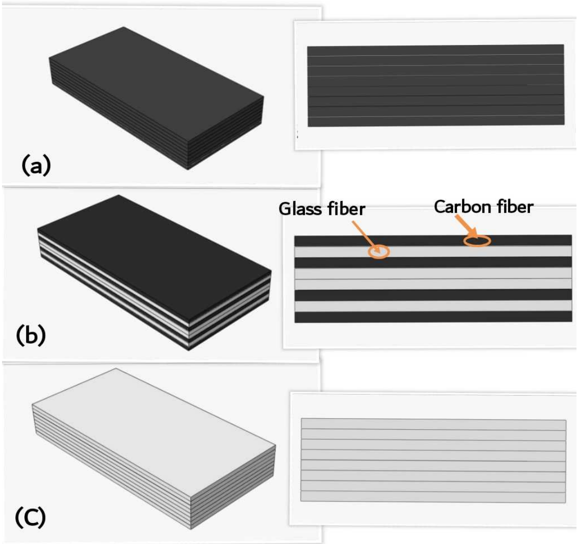


Fig.2. Schematic view of a) [C]8 b) [CGCG]s c) [G]8

In order to achieve a laminate without any porosity, the method of Vacuum Assisted Resin Transfer Molding (VARTM) has been used in the first step [15]. In this process, after placing the glass fibers in the vacuum bag (Figure 3) and creating a partial vacuum on it, the resin pass through the mold from inside the tube so that the whole bag is filled evenly. The produced face-sheet includes 8 layers of glass fiber woven with epoxy resin. The fabricated samples are vacuum placed for 12 hours at room temperature to be completely dried. Eventually, the samples are then placed in an oven at temperature of 60 oC for 4 hours. All laminates have 2 mm thickness.

Fig.3. Vacuum bag pump

4. M-shaped core Sandwich panel fabrication

The next step is to build sandwich panel with novel M-shaped core. The hybrid composite sandwich panel consists of two face-sheets and M-shaped lattice core (Figure 4). The M-shaped core is composed of three female parts and three male parts that every part has three trapezoidal unit cells. The truss-shaped core components have been designed as male and female parts in way that be assembled to each other without any need to glue. The dimensions of the female and the male parts have been shown in Figure 5.

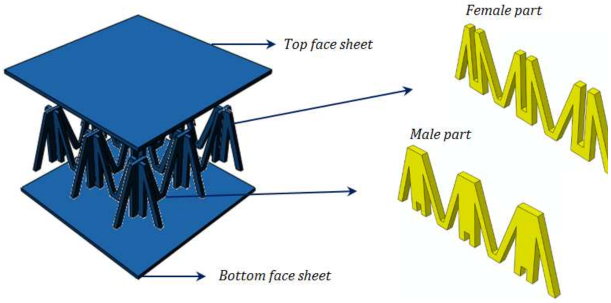
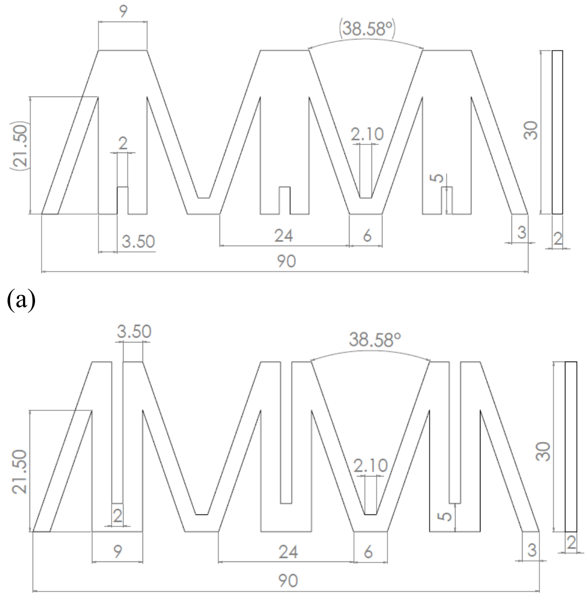


Fig.4. Configuration of composite sandwich panel with M-shaped lattice core



(a)

(b)

Fig.5. Dimensions of a) male and b) female part (in mm)

After fabricating laminates they are cut by water jet cutting operation to make the female parts and male parts according to the construction plan (Figure 6). Then, the resulting patterns were assembled into each other with male-female fitting to produce a M-shaped lattice core (Figure 7). As seen in Figure 4, the two face-sheets, which have dimensions of 90mm length, 90mm width and, 2mm thickness, are placed on the top and bottom of the core with epoxy resin. To attach the laminates to the core, sandwich panels are placed inside the oven. In order to make a strong connection between the core and plates, the samples should be placed inside the oven for 9 hours at 40 oC for more complete cooking. To perform the mechanical experiment on the panels, three sandwich panel have been fabricated for each experiment. Finally, [C]8, [G]8, and [CGCG]s sandwich panels were fabricated with dimensions of 90mm × 90mm × 34mm (Figure 8). Then polyurethane foam, which is obtained by combining two materials: polyol and is ocyanate, with a density of 80 Kg/m3 has been used to fill the empty space between the M-type core and the sandwich panel surfaces. Finally, the foam-filled sandwich panel was made as shown in Figure 9.

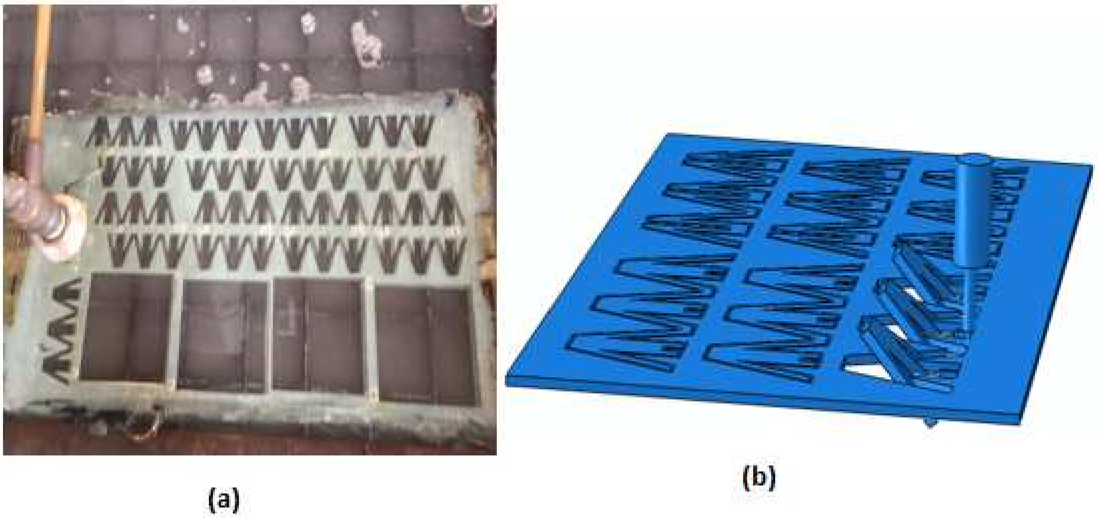


Fig. 6. Cutting laminates by waterjet machine a) Real view b) Schematic view

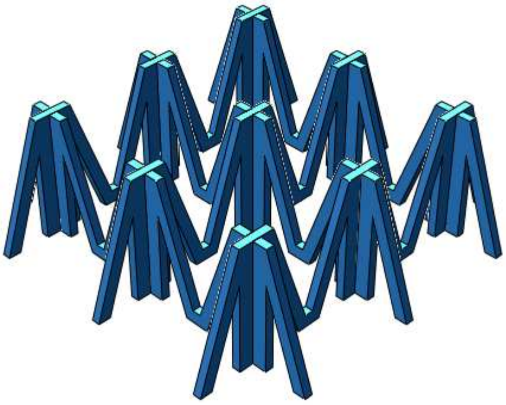


Fig.7. schematic view of M-shaped core

Fig.8. $[C]_8$, $[G]_8$, and $[CGCG]_s$ composite sandwich panels

Fig.9. $[C]_8$, $[G]_8$, and $[CGCG]_s$ composite sandwich panels with polyurethane foam

5. Experimental tests

All of the mechanical tests in the present research were done by a SANTAM testing machine with axial actuator. ASTM organization is an international standard development organization that Its task is to publish technical standards for many different industries. SANTAM Engineering Design Company is a manufacturer of laboratory testing devices under the ASTM standard, and all pressure and bending tests were performed with this devices. The SANTAM has a static capacity of 150 KN, with a maximum stroke of 300 mm. Aappropriate movement rate of the movable head of the testing machines is between 0.5 to 10 millimetres per minute [12]. In this study, the speed rate of 0.5 mm/min has been applied through all types of mechanical tests to get the maximum accuracy for taking pictures from different failure modes.

5.1. Tensile test

In order to determine the mechanical properties of the $[C]_8$, $[G]_8$, and [CGCG]s composite sandwich panels, the tensile test on rectangular specimens with dimensions of 250mm×25mm×2mm were conducted according to ASTM D-3039by using SANTAM STM-150 hydraulic device as shown in Figure 10. The constant movement rate of movable head of the testing machine was 0.5 mm/min.

(a) (b) (c)

Fig. 10. Tensile test on the sandwich panela) $[C]_8$, b) $[G]_8$ and c) $[CGCG]_s$

5.2. Three-point bending test

In order to determine the flexural behaviour of the hybrid composite sandwich panel, three-point bending test using a cylindrical rod with a 9 mm radius is implemented. The force-displacement curves of the $[C]_8$, $[G]_8$, and $[CGCG]_s$ composite panel are obtained. It is necessary to mention that the three-point bending tests in the current study were performed by a SANTAM STM-150 testing machine with axial actuators. Figure 11 shows the specimen mounted on the testing machine. Also, figure 12 shows the different foam-filled sandwich panels under three-point bending tests.

(a) (b) (c)

Fig.11. Three-point bending tests on the sandwich panel a) $[C]_8$, b) $[G]_8$ and c) $[CGCG]_s$

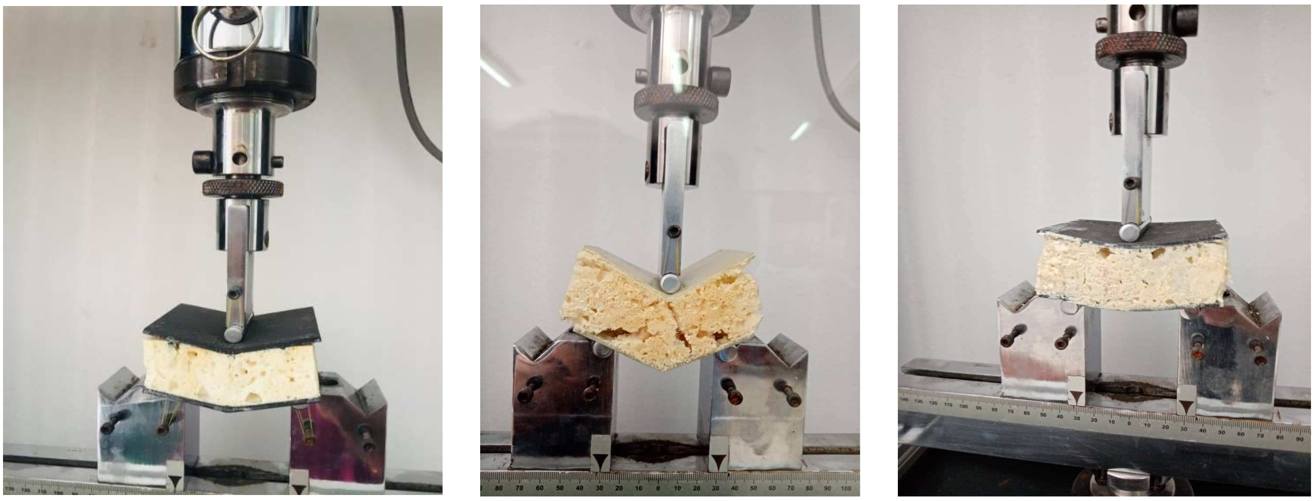

(a) (b) (c)

Fig. 12. Three-point bending tests on the foam-filled sandwich panel a) $[C]_8$, b) $[G]_8$ and c) $[CGCG]_s$

5.3. Compressive test

In order to determine the compressive behaviour of the hybrid composite sandwich panel, single laps flatwise compressive test was conducted on the M-shaped core sandwich panels. The force-displacement curves of the $[C]_8$, $[G]_8$, and [CGCG]s composite panels are obtained. Flatwise compression tests were performed according to ASTM C365 test standard. For the flatwise compression test, the specimen with an area of 90 mm × 90 mm was put on a self-aligning spherical bearing block. Figure 13 shows the specimen mounted on the testing machine. Also, figure 14 shows the different foam-filled sandwich panels under compressive tests.


(a) (b) (c)

Figure 13. Compressive tests on the sandwich panel a) $[C]_8$, b) $[G]_8$ and c) $[CGCG]_s$

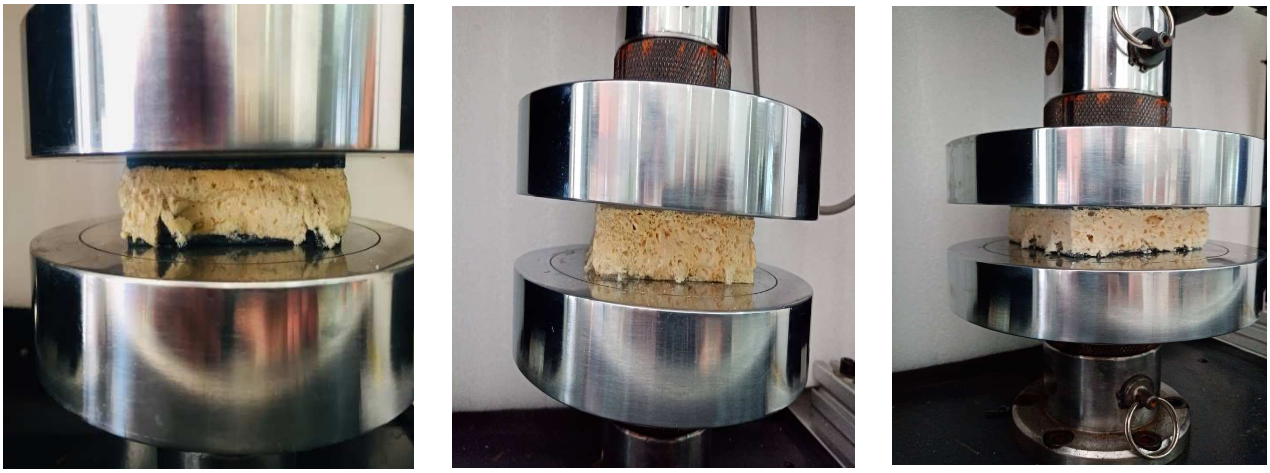

(a) (b) (c)

Figure 14. Compressive tests on the foam-filled sandwich panel a) $[C]_8$, b) $[G]_8$ and c) $[CGCG]_s$

6. Results and Discussion

6.1. Results of tensile strength

Figure 15 indicates force-displacement diagram that has been obtained from the experimental tensile test data for $[C]_8$, $[G]_8$ and $[CGCG]_s$ composite sandwich panel. According to the results of the tensile test, specimens $[C]_8$ had maximum tensile strength and toughness and, specimens $[G]_8$ shows the lowest tensile strength rate, while But by combining 50% of carbon fiber and 50% of glass fiber with a layered arrangement model $[CGCG]_s$ has higher tensile strength than specimens $[G]_8$ and less than specimens $[C]_8$.In other words, the properties of hybrid composite specimens $[CGCG]_s$ are a combination of the properties of $[G]_8$ and $[C]_8$.

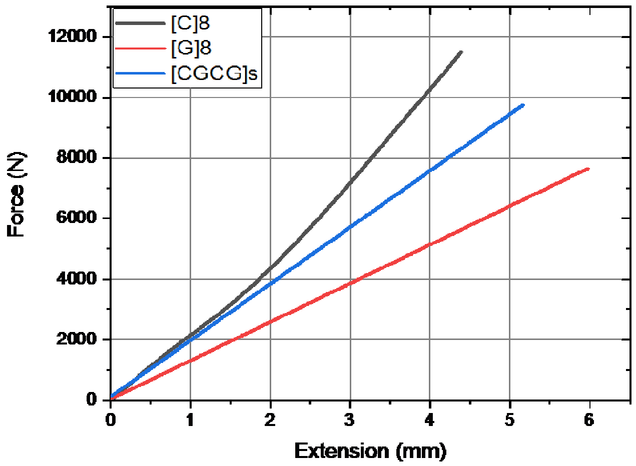


Fig. 15. Force-displacement diagram of $[C]_8$, $[G]_8$ and $[CGCG]_s$ sandwich panels under tensile test

6.2. Results of three-point bending test

In this section, the results of three-point bending test on different sandwich panels with M-shaped core have been presented. Figure 16 illustrates the force-displacement diagram of M-shaped composite sandwich panel exposed to a three-point bending load. This figure shows that the highest flexural strength is related to the carbon fiber sandwich panel $[C]_8$, in which the upper surface initially breaks and after a while the lower surface breaks. The results show that most of the bending load is tolerated by the upper and lower plates because after the failure of the plates until the end of the test, a sharp drop is observed in the force-displacement diagram. The force-displacement diagram of the glass fiber sandwich panel $[G]_8$ shows the lower failure zone at higher displacement which the initial failure occurring at the base of the cores and then the complete failure zone occurring after the plates fail. This behaviour indicates the ductile behaviour of the glass fiber sandwich panel $[G]_8$. Eventually, the force-displacement diagram for sandwich panel with hybrid carbon-glass fiber $[CGCG]_s$ shows that $[CGCG]_s$ has the a larger elastic region than $[C]_8$ and the larger plastic region than $[G]_8$.It was also found that the shear load is tolerated simultaneously between the plates and the cores and no sudden drop occurs after the plates break. Figure 17 illustrates the force-displacement curves for the foam-filled and non-foam-filled composite sandwich panel under the three-point bending test. It is figured out that polyurethane foam has a great influence on the bending behaviour of the sandwich panels and the peak load in the foam-filled sandwich panel is more than that in the foamless sandwich panels.

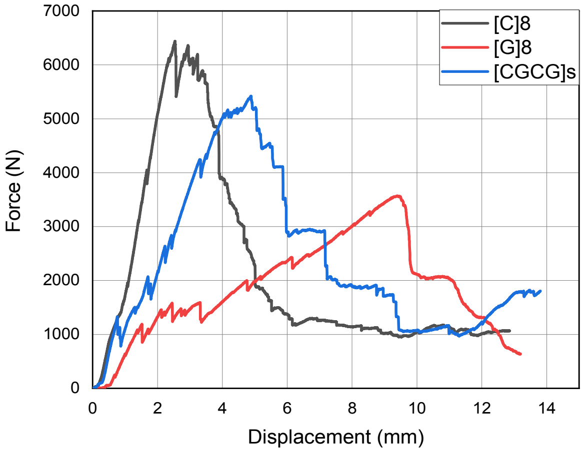


Fig. 16. Force-displacement diagram of $[C]_8$, $[G]_8$ and $[CGCG]_s$ sandwich panels under three-point bending test

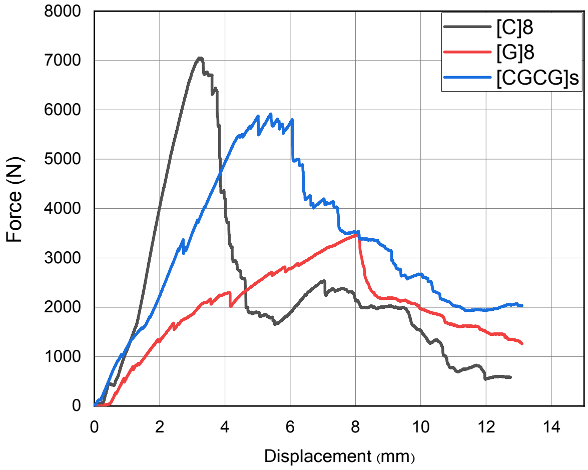


Fig.17. Effect of polyurethane foam on the flexural behaviour of $[C]_8$, $[G]_8$ and $[CGCG]_s$ sandwich panels

6.3. Results of compressive test

Figure 18 compares the flat-wise compressive behaviour of $[C]_8$, $[G]_8$ and $[CGCG]_s$ sandwich panels. According to the figure, the highest resistance to failure is related to the carbon fiber reinforced composite sandwich panel $[C]_8$ which slowly crosses the slope of the plastic area. The glass fiber reinforced composite sandwich panel $[G]_8$ diagram shows a yield strength close to $[C]_8$ except that the slope of the plastic area shows a more rapid sudden drop in force tolerance. The force-displacement diagram for sandwich panel with hybrid carbon-glass fiber $[CGCG]_s$ shows that the $[CGCG]_s$ has a lower yield stress point than $[C]_8$ and $[G]_8$ but it has a higher plastic slope than $[C]_8$ and $[G]_8$. Figure 19 illustrates the force-displacement curves for the foam-filled and non-foam-filled composite sandwich panel under the three-point bending test. It is figured out that polyurethane foam has great influence on bending behaviour of the sandwich panels and the peak load in the foam-filled sandwich panel is more than that in the foamless sandwich panels.

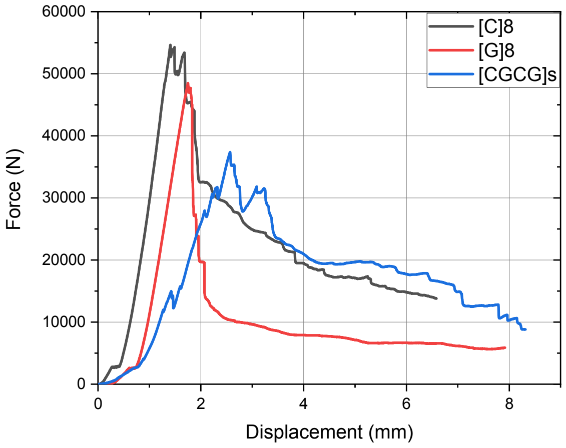


Fig.18. Force-displacement diagram of $[C]_8$, $[G]_8$ and $[CGCG]_s$ sandwich panels under compressive test

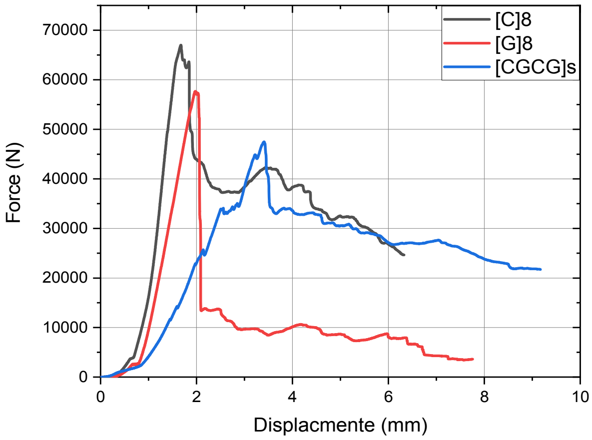


Fig.19. Effect of polyurethane foam on the compressive behaviour of $[C]_8$, $[G]_8$ and $[CGCG]_s$ sandwich panels

7. Conclusion

In this study, composite sandwich panels with a different arrangements of carbon and glass fiber, i.e. eight-layered carbon fiber $[C]_8$, eight-layered glass fiber $[G]_8$, and hybrid carbon-glass fiber $[CGCG]_s$, were fabricated by the vacuum-assisted resin transfer molding method. The mechanical responses under compression and three-point bending were experimentally tested. The results including strength, load capacity and failure models are compared and discussed. the Main conclusions are as follows:1-When the hybrid carbon-glass fiber sandwich panel $[CGCG]_s$ is subjected to stress, the damage to it does not occur abruptly. First, the carbon fibers fail, and with that failure, the force is transferred to the glass fibers, and the final failure will occur with the destruction of the matrix. 2-Sandwich panels with M-shaped core due to the shape of the structure have a symmetrical and homogeneous collapse mechanism in the core. 3-Based on the present study, injecting the

Polyurethane foam among the core enhanced the ultimate compressive and bending loads and absorber features of sandwich panels. 4-The use of hybrid sandwich panels has a great impact on controlling fuel consumption, reducing environmental pollution, and as well as lower costs than pure fibers.

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