Journal of Mechanical Science and Technology 37 (11) 2023

Original Article
DOI 10.1007/s12206-023-1020-6

Keywords:
· Aircraft materials
· Composite structures
· Compression
· Flexural stiffness
· Static indentation

Correspondence to:
Nagwa Elzayady
goga.2008@yahoo.com

Citation:
Jatulis, M., Elghandour, E., Elzayady, N. (2023). Evaluation of the mechanical properties of aircraft composite materials after indentation. Journal of Mechanical Science and Technology 37 (11) (2023) 5813~5821.
http://doi.org/10.1007/s12206-023-1020-6

Received July 23rd, 2022
Revised July 25th, 2023
Accepted August 11th, 2023

† Recommended by Editor Chongdu Cho

Evaluation of the mechanical properties of aircraft composite materials after indentation

Marius Jatulis[1], Eltahry Elghandour[1] and Nagwa Elzayady[2]

[1]California Polytechnic State University, San Luis Obispo, California, USA, [2]Institute of Aviation Engineering and Technology, Giza, Egypt

Abstract There is a growing demand to comprehend the orthotropic properties of composite sandwich structures. Indentation stress is often experienced on the surfaces of sandwich beams, particularly during maintenance procedures. The objective of the present investigation is to evaluate the performance of these structures under such circumstances. The mechanical behavior of the composite sandwich structures is assessed by analyzing the results of edgewise compression and flexure tests conducted after indentation. The experiments encompass variations in carbon composite face thicknesses, core types, and indentation depths. The overall outcomes highlight a notable effect of indentation, particularly in the case of foam-core sandwiches, which exhibit lower elasticity compared to honeycomb-core sandwiches. Interestingly, the specific properties of both foam and honeycomb core beams, relative to their weight ratios, are found to be comparable. Furthermore, the results demonstrate that sandwich beams with reduced face material display lower stiffness but higher flexibility, enabling them to greater resistance to damage.

1. Introduction

Composite sandwich structures play a vital role in various industries such as aerospace, marine, and automotive constructions [1]. Within these composites, it is well-established that the fibers experience lower strain compared to the matrix and exhibit greater resistance to stress [2]. In a sandwich structure, the load-bearing components are the outer composite face sheets, while an inner core is incorporated to establish a separation between the two face sheets. Consequently, this arrangement increases the moment of inertia of the structure, leading to enhanced strength [1]. The moment of inertia rises proportionally with the thickness of the sandwich. These structures exhibit superior stiffness and flexural strength when compared to non-sandwich counterparts consisting of the same constituents. Similar to an I-beam, the core of the sandwich structure bears the shear loading, while the two face sheets endure tension and compression loads [1]. The sandwich structure exhibits orthotropic properties, meaning that its material characteristics vary at a given point along three mutually perpendicular axes [3]. Various techniques can be employed for the manufacturing of face sheets, including resin injection and compression on mold, wet matrix laying-up, filament winding, and pultrusion [4]. A relatively recent method of manufacturing involves the use of prepreg woven plies, which can be cured under vacuum bagging techniques after the laying-up process. The sandwich structure is specifically designed to withstand specific service conditions, such as external work stresses or errors during maintenance. For instance, surface indentations resulting from the dropping or pressing of maintenance tools are examples of such circumstances. The direction of the applied load on the sandwich structure, considering its orthotropic properties, should be taken into account.

Several investigations have examined the impact of indentation on the performance of composite panels.

In a study conducted by Nettles et al. [5], a comparison was made between quasi-static indentation and low-velocity impact on prepreg carbon fiber composite laminates. The authors found no significant difference between the two strain rates tested, indicating that quasi-static indentation testing can effectively represent low-velocity impact. In another investigation by Rizo et al. [6], the focus was on examining the effects of indentation on composite panels consisting of foam core and glass fiber reinforced face sheets. The researchers concluded that the residual dent resulting from indentation can play a crucial role in determining the load-bearing capacity of these panels. Numerical modeling revealed that the area of plastic deformation initially expands in the radial direction. However, the face sheet alone is unable to evenly distribute the load in a radial manner, resulting in the deformation extending into the core material. In a study conducted by Johnson et al. [7], quasi-static indentation and low-velocity impact tests were performed on sandwich panels consisting of foam cores and CFRP (carbon fiber reinforced polymer) facings. The findings revealed that indenters with smaller contact areas caused perforation rather than mere indentation on the face sheet. The researchers confirmed that the constraint (clamping) of the panel had a significant influence on the type of damage observed, with smaller contact areas resulting in more concentrated damage. Other research endeavors have explored the impact of indentation at different strain rates on the bending properties of sandwich beams. Sadighi et al. [8] demonstrated that as the thickness of the sandwich beams increased, there was an increase in flexural stiffness. They also observed that the energy absorbed by the sandwich face sheets during bending deflection was significantly lower compared to the energy dissipated during indentation. Additionally, the study concluded that higher strain rates led to greater stiffness and increased energy absorption by the sandwich beams. Many investigations have focused on examining the compression behavior of sandwich structures under various load directions. Elzayady et al. [9-11] conducted studies specifically on edgewise compression for different sandwich configurations. In their experiments, they replaced the traditional core material with a composite corrugation core inserted between carbon composite face sheets. The researchers found a strong adhesion between the fiberglass composite corrugation core and the carbon composite face sheet in a hybrid sandwich structure [9]. However, they observed weak bonding between the carbon corrugation core and carbon facings, indicating limited interference between these components. They also established good adhesion between the glass core and glass face sheets. Notably, the sandwich member composed of pure fiberglass composites exhibited lower compression energy compared to the hybrid sandwich beam [10, 11].

Eltahry et al. [12] conducted a study demonstrating that sandwich structures incorporating corrugation composite cores exhibit higher absorbed compression energy compared to those with honeycomb cores. In another investigation by Elzayady et al. [13], edge-wise compression was examined for sandwiches with different facing sheet materials, including a bio-composite made of hemp-epoxy and a synthetic composite composed of carbon-epoxy. The researchers found that panels with carbon fiber composite facings exhibited higher strength values when honeycomb or foam cores were utilized, compared to those with bio-composite facings. However, they observed comparable results for both facing materials when a balsa wood core was used. In a separate study, Elhabak et al. [14] investigated the influence of indentation on fiber metal composite laminates (FMLs) under quasi-static and low-velocity strain rates. The researchers found that FMLs containing fiberglass (GLARE) exhibited superior impact resistance compared to those composed of Kevlar composite (ARALL). They also noted that the impact resistance of ARALL was influenced by the strain rate, demonstrating better resistance to low-velocity impacts compared to quasi-static indentation. However, there remains a lack of comprehensive information regarding the performance of composite panels after experiencing specific types of damage.

To address this research gap, the current investigation aims to comprehensively understand the effects of indentation on the performance of sandwich composite structures under different orientations. Multiple sandwich beams are utilized to facilitate effective comparisons among various alternatives. The characteristics of the sandwich samples encompass diverse core materials, the inclusion or omission of the adhesive layer, and variations in face sheet thickness. The flexural and edgewise compression properties are assessed both with and without indentation, considering different load orientations.

2. Experimental work

2.1 Material and method

2.1.1 Material

The face sheets utilized in the construction of the sandwich structures are fabricated using "Toray TC275-1" prepreg fabrics [15]. Two distinct materials are chosen for the cores: Nomex honeycomb [16] and PVC structural foam [17]. The bonding material employed for securing the core to the face sheets is an epoxy adhesive known as Mitsubishi Newport 102 [18]. Detailed specifications of all the materials, as per the respective datasheets [15-18], are provided in Table 1.

2.1.2 Method

2.1.2.1 Specimen manufacturing

The preparatory phase involves accurate cutting of the prepreg material and cores. It also includes precise preparation of the film adhesive to ensure adherence to required dimensions. Following this, a meticulous layup procedure is conducted, which is then followed by a carefully monitored curing process. The manufacturing process utilizes the vacuum bag technique to achieve optimal results. A curing cycle is established at 135 °C for complete curing, and an extended dwell time is implemented to enhance efficacy. The panels' configurations,

Table 1. Material specifications.

Material type	Tensile strength (MPa)	Tensile modulus (GPa)	Comp. strength (MPa)		Comp. modulus (GPa)	
Carbon laminate (TC275-1 fabric) [15]	650	45	445		42	
*H.C [16]	-	-	L	W	L	W
			0.76	0.42	33	22
Foam (12.7 mm) H80) [17]	-	-	1.2		85	
Epoxy (102HC) [18]	13	-	-		-	

*H.C [16]; honeycomb nomex is (12.7 mm)

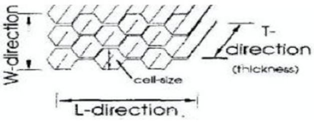


Table 2. Specifications of manufactured panels.

Panel no.	Face sheets (carbon fiber)	Core	Epoxy adhesive
Panel-1	2 layers	12.7 mm (½") nomex honeycomb	No
Panel-2	2 layers	12.7 mm (½") nomex honeycomb	Yes
Panel-3	1 layer	12.7 mm (½") nomex honeycomb	Yes
Panel-4	2 layers	12.7 mm (½") H80 foam	Yes

Fig. 1. Standard testing samples.

outlined in Table 2, remain consistent throughout the manufacturing process. Each panel utilizes face sheet material derived from the same prepreg carbon fiber composite, ensuring uniformity. All panels are systematically manufactured to a standardized size of 58 × 61 cm. Once completed, the fully cured panels are precision-cut to conform to standardized testing dimensions as illustrated in Fig. 1.

2.1.2.2 Fixture design and manufacturing:

To facilitate the indentation test, a custom fixture is precisely designed specifically for the Instron testing frame. The fixture's primary purpose is to securely hold a 19 mm (3/4") diameter hemispherical indenter within the hydraulic jaw of the Instron machine, ensuring precise alignment with the desired displacement direction. The fixture is made with great care using square tube steel stock. It includes a 19 mm (3/4") - 10 hex nut and steel bar stock to do its job properly. The steel bar stock serves as the tab for the hydraulic jaws to firmly grip onto, ensuring stability during testing. The preparation process for the fixture is carefully outlined and organized, adhering to a systematic approach that guarantees accuracy and reliability. The steps involved in preparing the fixture are presented as illustrated in Fig. 2.

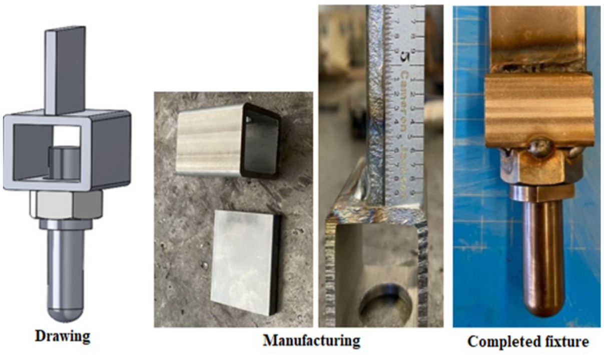


Fig. 2. Indenter fixture preparation.

3. Testing

A number of specimen groups are prepared for the different tests with four samples from each panel to confirm the results. The extracted result values in the current investigation are the average of the results. Table 3 includes the specifications of all test specimens. Multiple specimen groups are prepared for various tests, with four samples obtained from each panel to ensure result reliability. The extracted result values represent the average of the obtained results. Detailed specifications of all samples are provided in Table 3.

3.1 Indentation test

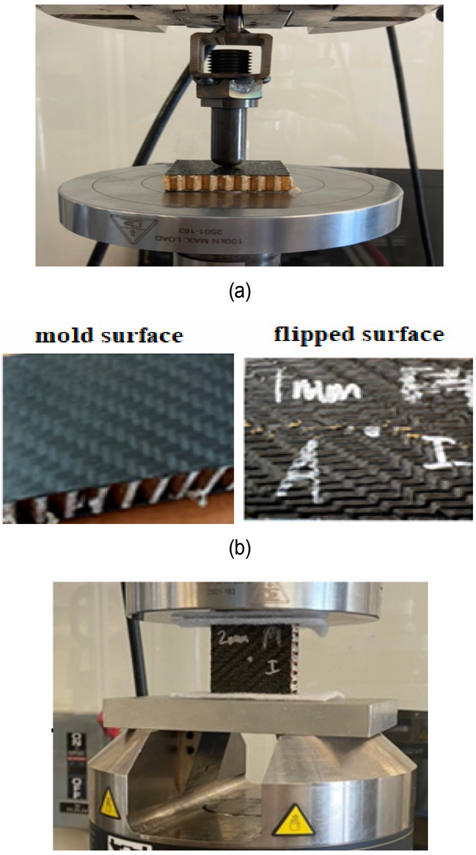
The first test conducted was the indentation test, which was applied until failure for all the different sandwich configurations, including the core materials without facings. The test specimens were positioned according to the designated locations shown in Fig. 3(a). The indentation test was performed using the Instron testing frame, with a consistent crosshead speed of 1 mm/min. Square cross section samples, following the specifications outlined in Table 3, were tested from each panel.

3.2 Compression test

New sets of samples were prepared according to the specifications presented in Table 2. Some specimens underwent indentation at different levels, while others remained unindented. The samples were positioned as shown in Fig. 3(a).

Table 3. Specifications of testing samples.

Test	Standard specimens from	Core thick (mm)	One face thick. (mm)	Total height (Thick.) (mm)	C.S. (L×W) (mm×mm)
Indentation	Panel-1	Thick. 12.7	0.63	13.96	50.8×50.8
	Panel-2		0.67	14.04	
	Panel-3		0.35	13.4	
	Panel-4		0.67	14.04	
Compression	Panel-1		0.63	13.96	50.8×50.8
	Panel-2		0.67	14.04	
	Panel-3		0.35	13.4	
	Panel-4		0.67	14.04	
3-point bending	Panel-1		0.63	13.96	152.4×50.8
	Panel-2		0.67	14.04	
	Panel-3		0.35	13.4	
	Panel-4		0.67	14.04	



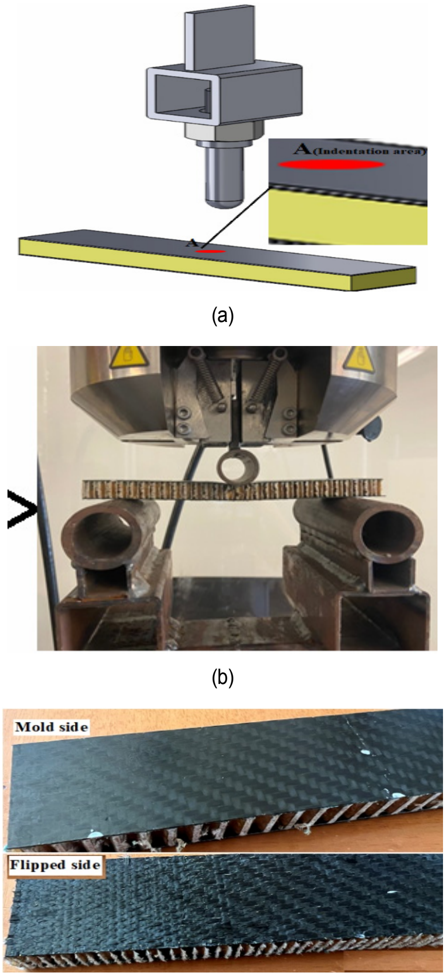
(a)

(b)

(c)

Fig. 3. (a) Indentation testing; (b) edgewise compression after indentation; (c) surface nature.

For each of the four sandwich configurations, there were control groups without indentation, groups with 1 mm indentation (including one group with mold smooth surface and another group with a flipped rough surface), and a group with 2 mm indentation. Fig. 3(b) presented both the mold and flipped surfaces of the specimens.



(a)

(b)

(c)

Fig. 4. (a) Specimen under indentation; (b) 3-point bend testing after indentation; (c) surface nature of both sandwich sides.

Subsequently, all specimens were subjected to edgewise compression testing, where the load was applied parallel to the surface affected by indentation (Fig. 3(c)). This testing aimed to further investigate performance variations under different load orientations. A compression test, following ASTM C364/C364M-16 [19] standards for sandwich constructions, was conducted with a constant displacement rate of 5 mm/min.

3.3 3-point bending test

The composite sandwich structures underwent 3-point bend testing, utilizing an Instron testing frame and a 3-roller fixture, in accordance with ASTM C393 [20]. The samples adhered strictly to the specifications outlined in Table 2. The tested samples were divided into several groups: a control group without indentation, a group with 1 mm indentation (including a subgroup with flipped surface indentation), and a group with 2 mm indentation.

During the testing process, Fig. 4(a) displayed the samples while undergoing indentation, while Fig. 4(b) depicted the samples during the bending phase. Furthermore, Fig. 4(c) showcased the mold and the flipped surfaces of the samples.

Indentation was precisely centered on the face sheet, indicated by the red area at the midpoint of the specimen's length and width. A flat compression platen was used to indent the specimens to the specified depth, employing a consistent rate of 1 mm/min, before proceeding with the bending test. After the indentation test, the flexural testing was conducted with the load direction perpendicular to the indented surface. The testing was carried out at a rate of 2 mm/min.

4. Results and discussion

4.1 Results of indentation

The average results of indentation tests are presented graphically in Fig. 5. The graph indicates that the honeycomb core without facings exhibits the highest displacement with the least applied force. The inclusion of adhesive between the facings and cores (panel-1 vs. panel-2) does not yield a substantial impact. However, the thickness of the facing sandwiches does play a role, as thicker facings are capable of withstanding higher ultimate forces before failure, albeit at the cost of reduced flexibility (panel-2 vs. panel-3). Notably, the choice of core material has a significant influence on the indentation force. The sandwich samples with a foam core from panel-4 experience the least displacement and withstand the highest force before failure, indicating lower compressibility. In terms of the numerical results, the indentation force for sandwich beams with a honeycomb core is more than five times greater than that of the pure cores. Transitioning from a cellular honeycomb core to a bulk foam core nearly doubles the force resistance of the sandwiches (force increases from 481 to 1011 N).

4.2 Failure modes of indentation

Based on Fig. 6, it is evident that the foam core exhibits low elastic recovery in the indentation area. The fracture mode of the foam is characterized by a localized compressed region surrounded by cracks. In contrast, the honeycomb core demonstrates high elastic recovery, with damage manifesting as distorted honeycomb cell geometry. In other words, the hexagonal cell shape becomes distorted. These fracture modes align with the test results depicted in Fig. 5.

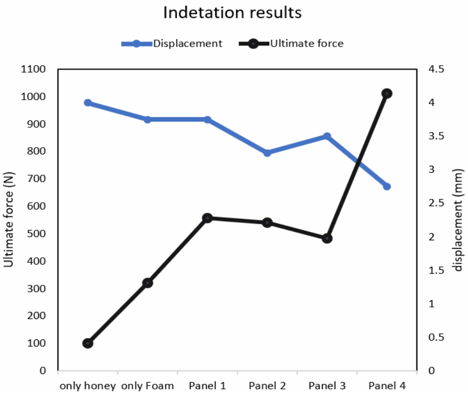


Fig. 5. Results of the indentation test.

In the case of the sandwich structure, the carbon facing experiences deflection with the maximum value at the center of indentation, while the core beneath the facing undergoes some distortion.

4.3 Results of edgewise compression

The indentation and subsequent edgewise compression tests were conducted on selected compression specimens. The results were analyzed and plotted in Figs. 7 and 8, repre-

Fig. 6. Damage after indentation.

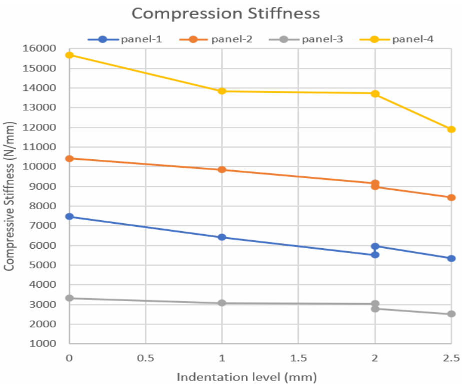


Fig. 7. Results of the compression stiffness.

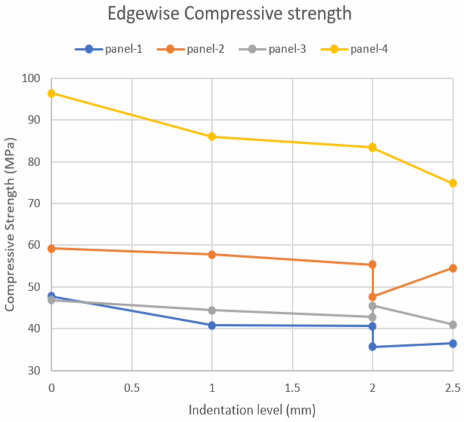


Fig. 8. Results of the compression strength.

senting the compression stiffness and strength, respectively. Irrespective of the specific sandwich configuration, it is evident from both Figs. that the compressive properties of the sandwich decrease with an increase in the levels of indentation. In addition, the inclusion of adhesive between the honeycomb core and the facings has a positive influence on the compression properties. In contrast, it was previously noted that the adhesive does not significantly affect the indentation resistance, as shown in Fig. 5. This highlights the importance of load direction in sandwich design. Whereas, the load direction in edgewise compression tests is parallel to the indented area (out of plane).

The presence of adhesive improves the load transfer between the facings and core, which is essential for effective load distribution during edgewise compression. The addition of adhesive results in an approximate 1.4-fold increase in both the compressive stiffness and strength of the sandwich at all levels of indentation. For example, when comparing panel-1 and panel-2, at a 1 mm indentation, the stiffness increases from 6412 N/mm to 9842 N/mm, while the strength increases from 40 MPa to 59 MPa. The decrease in compression properties remains relatively consistent across various levels of indentation. The greater thickness of the facings enhances the compression capacity of the sandwich, as evidenced by the comparison between panel-2 and panel-3 results. Moreover, the type of core material significantly influences the compression properties. Replacing a honeycomb core with a foam core at 1 mm indentation leads to an approximate 45 % increase in both stiffness and strength. Therefore, it is evident for the indented samples that the indentation level, facing thickness, and core type all play vital roles in determining the edgewise compression properties of the sandwich structure.

4.4 Failure modes edgewise compression

The fracture in the specimens primarily occurs near the mid-height plane, as depicted in Fig. 9. The location of fracture is likely influenced by the damaged area caused by indentation, which is typically positioned at the mid-plane of the specimen's height. Furthermore, this plane experiences relatively less gripping support, being farthest from both the upper and lower cross-head machine. This failure mode aligns with previous findings reported by Elzayady et al. [9-11].

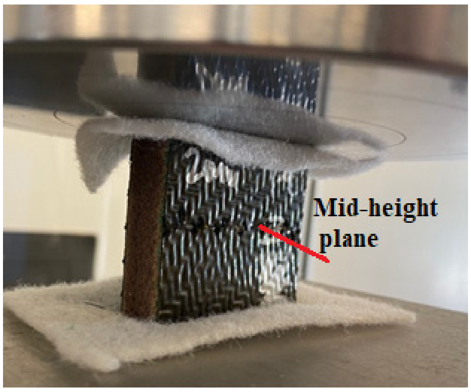


Fig. 9. Edgewise compression failure.

4.5 Results of 3-point bending

The average values of the flexural stiffness and flexural ultimate force are presented in Figs. 10 and 11, respectively. The curves representing the different panels in both figures demonstrate a flexural behavior similar to the trends observed in the edgewise compression tests. Across all sandwich construction types, both the flexural stiffness and flexural ultimate force decrease as the indentation level increases. The thickness of the face sheets and bonding layers between the core and facings have minimal effects on the flexural properties, which are less pronounced compared to their impacts on edgewise compression properties. This observation underscores the substan-

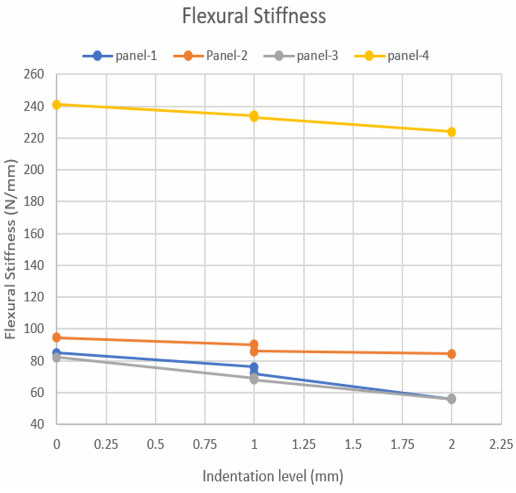


Fig. 10. Results of the flexural stiffness.

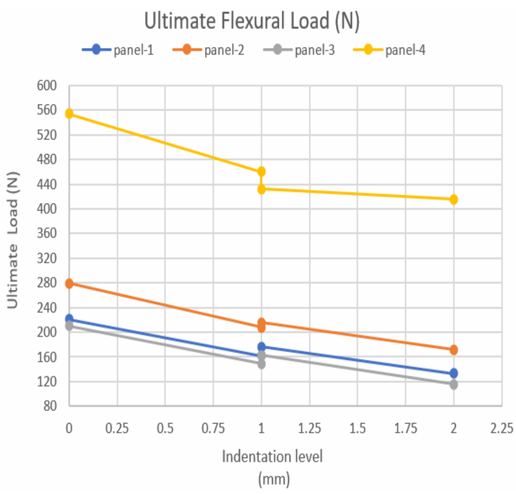


Fig. 11. Results of the flexural ultimate force.

tial impact of load direction on the behavior of the sandwich structure. In the bending test, the load is applied perpendicular to the indented area.

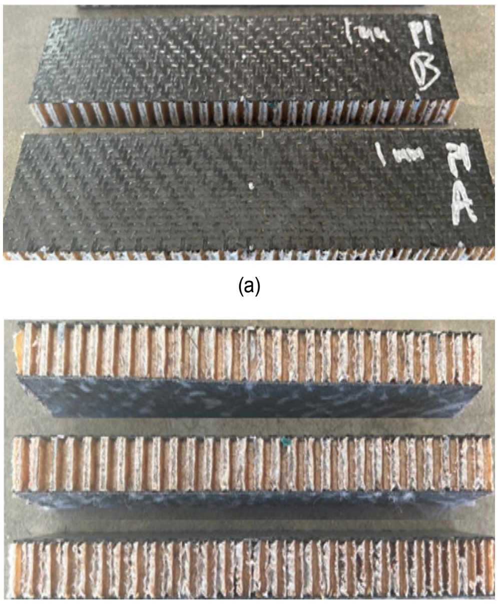
On the other hand, the core material has the greatest influence on the flexural properties. The foam-core sandwiches (Figs. 10 and 11) exhibit high flexural values before failure, comparable to those of a cellular-honeycomb core sandwich. The surface characteristics of the samples also play a role in influencing the flexural properties. Testing is conducted on both a smooth surface and a textured rough surface by flipping the sample. It should be noted that this condition is applied specifically for the case of a 1 mm indentation level. The results show that the flexural force values are slightly higher for the smooth surface compared to the textured surface, with an increase ranging from 4 % to 8 % in both stiffness and force. This suggests that the smooth side withstands indentation and damage better than the textured side, possibly due to the sliding action between the indenter and the smooth surface. However, it is important to note that the smooth surface of the sandwich structure is the side that comes into contact with the mold surface during manufacturing using the vacuum technique.

4.6 Failure modes 3-point bending

During the 3-point bending testing, an interesting observation was made: certain specimens emitted audible cracking sounds, even though no visible failure mode was apparent in the carbon facing sheets (as depicted in Fig. 12(a)). However, upon closer inspection, it was evident that the core of the samples exhibited visible damage areas from the sides (Fig. 12(b)). In other specimens, a crack occurred in the midsection of the top face sheet (Fig. 13). The crack observed occurred on the tension side of the specimen. This is because during the bending test, the mid-section of the top face sheet experiences compression, while the bottom face sheet experiences tension. Notably, the cracks were more pronounced in samples with deeper indentations (2.5 mm). The increased indentation depth disrupts the bond between the face sheet and core, reducing the resistance to cracks. Additionally, some localized damage to the core and face sheet was observed in the middle of the specimen.

Through a comparative analysis of the findings presented in this article, it is evident that composite sandwich structures with foam and honeycomb cores, coupled with two layers of carbon face sheets, exhibit the highest mechanical properties among various sandwich constructions. Considering the importance of overall weight in aerospace applications, the specific property-to-weight ratio becomes a suitable metric for comparing alternatives.

In terms of weight, the foam-core sandwich with identical carbon composite face sheets weighs approximately 1.3 times that of the honeycomb-core sandwich. Consequently, to obtain their specific properties, the output values of the foam-core sandwich should be divided by this magnitude (1.3). For instance, at a 2 mm indentation, the actual compression stiffness of the foam-core sandwich is 11907 KN/mm, whereas that of the honeycomb-core sandwich is 8438 KN/mm. However, when considering the weight factor, the specific stiffness-to-the weight ratio of the foam-core beam is 1.08 times that of the honeycomb-core sandwich. Therefore, both configurations (panel-2 and panel-4) offer comparable specific properties to their weight ratios and are preferable choices for applications involving high stresses.



(a)

(b)

Fig. 12. (a) Failure without visible cracks at the faces; (b) failure at the sides is obvious in the core.

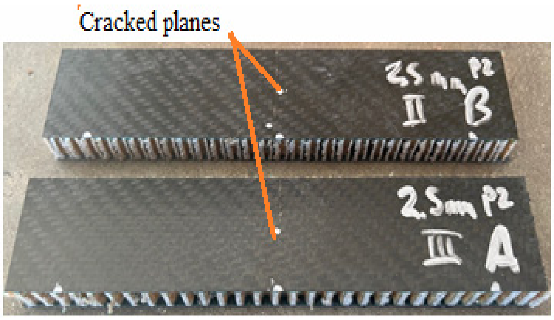


Fig. 13. Face sheet crack.

On the other hand, when high elasticity and low stiffness are required, the sandwich with a reduced amount of face sheet material combined with a honeycomb core (panel-3) is recommended.

5. Conclusions

The adhesive layer is crucial for maintaining performance after indentation damage. Specimens with the adhesive layer between face sheets and core showed better overall performance in bending and compression tests. Indentation resulted in less stiffness and ultimate strength degradation.

The quantity of face sheet material in composite sandwich structures has a significant impact on their behaviour. When the faces have a reduced amount of material, they exhibit improved elasticity and enhanced resistance to damage. This results in decreased face sheet stiffness, enabling more extensive flexing and deformation before plastic deformation and cracking occur. Consequently, utilization of an appropriate amount of face sheet material in situations where lower strength is adequate results in weight and cost reduction. It also enhances performance after indentation. Conversely, when high stiffness and strength are necessary, additional face sheet material can be utilized.

The core material type significantly affects sandwich structure performance. Foam-core beams have lower elasticity than honeycomb-core beams, leading to increased damage and performance decline after indentation. However, foam-core sandwich structures demonstrate remarkable strength and stiffness properties, even though they are heavier than honeycomb cores. When evaluating weight, both core types provide comparable specific properties to weight ratios, making them advantageous choices for service conditions that prioritize these factors.

The orientation of the load after indentation affects sandwich structure behavior significantly. Edgewise compression properties are particularly affected as the load is parallel to the indented load. In contrast, flexural properties are less affected as the load direction is perpendicular to the indented area in both flexure and indentation.

The surface characteristics of the sandwich faces influence the resistance to indentation. The smooth side of the sandwich demonstrates slightly better resistance to indentation and damage compared to the textured side.

References

[1] F. C. Campbell, *Structural Composite Materials*, ASM International (2010).

[2] B. Agarwal, Broutman, J. Lawrence and K. Chandrashekhara, *Analysis and Performance of Fiber Composites*, 4th Ed., Wiley (2017).

[3] G. H. Staab, *Laminar Composites*, 2nd, Butterworth-Heinemann (2015).

[4] D. B. Miracle and S. L. Donaldson, *ASM Handbook, Composites*, ASM International (2001).

[5] T. Nettles and M. J. Douglas, *A Comparison of Quasi-Static Testing to Low-Velocity Impact Testing*, American Society for Testing and Materials International, ASTM STP 1416 (2002) 116-130.

[6] V. Rizov, A. Shipsha and D. Zenkert, Indentation study of foam core sandwich composite panels, *Composite Structures*, 69 (1) (2005) 95-102.

[7] Johnson and E. A. Flores, Quasi-static indentation and low-velocity impact on polymeric foams and CFRP sandwich panels with polymeric foam cores, school of mechanical, aerospace and civil engineering, *Ph.D. Dissertation*, University of Manchester (2009).

[8] M. Sadighi, H. Pouriayevali and M. Saadati, *Indentation Energy in Bending of Sandwich, Beams with Composite Laminated Faces and Foam Core*, Dept. of Mechanical Engineering, Amirkabir University of Tech., Tehran, I.R. Iran (2022) http://www.escm.eu.org/ docs/eccm13/1906.pdf.

[9] N. Elzayady and E. Elghandour, Design optimization to improve the performance of the aircraft composite structures, *Journal of Mechanical Science and Technology*, 35 (10) (2021) 4381-4388.

[10] N. Elzayady and E. Elghandour, Compression behavior of composite sandwich panels with corrugated core, *International Journal of Sustainable Materials and Structural*, 5 (3) (2021) 193-205.

[11] N. Elzayady and E. Elghandour, Compression capacity of corrugated core hybrid composite sandwich structure, *Key Engineering Materials*, 821 (2019) 47-53.

[12] E. Elghandour and N. Elzayady, Comparison between honeycomb and composite corrugated cores in sandwich panels under compression loading, *International Journal of Sustainable Material and Structural Systems*, 5 (1-2) (2021) 179-192.

[13] N. E. Elzayady and E. I. Elghandour, Fracture resistance of composite structures from hemp bio-fibers, *Journal of Advanced Engineering Trends*, 40 (2) (2021) 137-147.

[14] A. M. Elhabak, A. Nabil, M. Adly and N. Elzayady, Behavior of hybrid composite structure under low impact velocity, *Journal of Engineering and Applied Sciences*, 15 (14) (2020) 2772-2780.

[15] Toray Advanced Composites, *Toray TC275-1, Datasheet TORAY_TC275-1_PDS_v.3.0,* Toray Advanced Composites (2020).

[16] Euro-Composites, *Mechanical Properties of ECA Honeycomb (Metric Test Specimen Thickness 12.7 mm),* Euro-Composites (2002) EC 536-13e.

[17] Diab International, *Divinycell H., Grade Technical Manual Datasheet, H Manual*, Diab International (2021).

[18] Mitsubishi Chemical, *Newport 102 Epoxy Film Adhesive Datasheet*, Mitsubishi Chemical (2018) PL- 102-011718.

[19] ASTM C364/C364M-16, *Standard Test Method for Edgewise Compressive Strength of Sandwich Constructions*, ASTM International, West Conshohocken, PA (2016).

[20] ASTM C393/C393M-00, *Standard Test Method for Flexural Properties of Sandwich Constructions*, ASTM International, West Conshohocken, PA (2000).

Marius Jatulis is a postgraduate student at the Mechanical Engineering Department of California Polytechnic State University, San Luis Obispo (Cal Poly SLO), USA. He completed his undergraduate studies at the same university. Marius obtained his Master's Degree in 2022. Email: mjatulis@calpoly.edu.

Eltahry Elghandour is a Professor in the Mechanical Engineering Department at California Polytechnic State University, San Luis Obispo (Cal Poly SLO), USA. He holds an M.Sc. and Ph.D. in Mechanical Design and Production Engineering, both obtained from Helwan University in 1989 and 1995, respectively. Professor Elghandour specializes in composite materials analysis, manufacturing, fatigue and fracture mechanics, and advanced finite element analysis. With a rich background in teaching and research, he has accumulated twenty-seven years of experience at the university level. Email: eelghand@calpoly.edu, phone: 805-756-1728.

Nagwa Elzayady is an Associate Professor of Mechanical and Aerospace Engineering at the Institute of Aviation Engineering and Technology (IAET) in Giza, Egypt. She holds an M.Sc. and Ph.D. in Mechanical Design and Production Engineering, both obtained from Cairo University in 2001 and 2012, respectively. Dr. Elzayady specializes in engineering materials analysis, composite materials, manufacturing, and testing. She has amassed ten years of experience in teaching and research at Cairo University (2000-2009) and another ten years at IAET (2010-2020). Additionally, she gained professional experience spanning from 1994 to 2004 at the Arab Organization for Industrialization (AOI) in Egypt. Email at goga.2008@yahoo.com, phone: +2 01022399953.