THE EFFECT OF VARIATIONS IN PVC FOAM CORE THICKNESS ON THE FAILURE ANALYSIS OF BENDING TEST IN SANDWICH COMPOSITE

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ABSTRAK

Core komposit *sandwich* merupakan salah satu bagian yang berperan sebagai material tambahan. Meskipun *core* lebih tipis, namun harus menghasilkan komposit yang kaku, kuat, dan ringan, dan semakin tinggi nilai kekuatan lentur yang diperoleh. Penelitian ini bertujuan untuk mengamati dan menganalisis pengaruh ketebalan *core* terhadap kekuatan *bending* dan mendapatkan modulus elastisitas serta menganalisa hasil patahan komposit *sandwich* setelah dilakukan pengujian *bending*. Bahan yang digunakan adalah resin polyester, serat karbon twill 240 gsm dan core PVC foam. Variasi ketebalan core 2 mm, 3 mm, 5 mm, 8 mm, dan 10 mm. Metode yang digunakan adalah *vacuum bagging*. Pengujian yang dilakukan adalah uji bending dengan menggunakan standar ASTM C393. Nilai kekuatan bending komposit *sandwich* tertinggi diperoleh pada variasi ketebalan core 2 mm yaitu sebesar 81,34 MPa, sedangkan nilai kekuatan bending terendah terdapat pada variasi ketebalan *core* 10 mm, yaitu sebesar 13,08 MPa.

Kata kunci: komposit *sandwich*, ketebalan inti, kekuatan lentur, modulus elastisitas, pengantongan vakum, busa PVC

ABSTRACT

The composite sandwich core is one of the parts that act as an additional material. Despite the thinner core, it should produce a stiff, strong, and lightweight composite, and the higher the bending strength value obtained. This study aims to observe and analyze the influence of core thickness on bending strength and obtain elastic modulus as well as analyze the results of sandwich composite fracture after bending testing. The materials used are polyester resin, 240 gsm twill carbon fiber and core PVC foam. Variations in core thickness of 2 mm, 3 mm, 5 mm, 8 mm, and 10 mm. The method used is vacuum bagging. The tests carried out are bending tests using the ASTM C393 standard. The bending strength value of sandwich composite was obtained at a core thickness variation of 2 mm, which was 81.34 MPa, while the lowest bending strength value was found in a core thickness variation of 10 mm, which was 13.08 MPa.

Keywords: *sandwich composite, core thickness, bending strength, modulus elasticity, vacuum bagging, PVC foam*

1. INTRODUCTION

The composite materials industry continues to evolve in response to increasing demand for materials that are lightweight and strong across various applications. One innovation in this field is the use of PVC foam as the core of sandwich composites. PVC foam is known for its low density and its ability to provide a lightweight yet strong structure. Particularly in aerospace, automotive, and construction applications, sandwich composites with PVC foam cores have become the preferred choice to meet design requirements prioritizing strength and weight [1]. In the advancement of modern times, there is a need for materials that are lightweight yet possess high mechanical strength characteristics. To meet these requirements, composite materials have been developed. One example of their application is in the automotive sector, such as in bumpers, which serve to protect both the driver and the vehicle's engine during collisions. Bumpers themselves currently utilize materials containing FeCr, but they still have some drawbacks, particularly in terms of acceleration due to their perceived heavy weight and high cost [2]. Presently, technology is progressing rapidly, with many innovations in new materials, especially in the field of composite materials, offering numerous benefits [2]. Research conducted by Bennbaiba et al. (2023) studied composite plastic hybrids for automotive front bumper beams. In car bumpers, materials are required to be thin but capable of withstanding impact and bending loads. The study revealed that sandwich composites with foam cores absorb impact energy more effectively compared to non-composite materials [3].

The development of sandwich composite materials is continuously pursued by researchers, aiming to achieve desired properties or characteristics. One area of extensive research in sandwich composites is the core, commonly referred to as the sandwich composite core. Variations in core materials within sandwich composites are studied extensively. However, changes in core thickness can influence load distribution, structural stiffness, and overall bending strength of the composite [4]. Therefore, further research can be conducted to understand the influence of varying PVC foam core thicknesses on the bending strength of sandwich composites. The vacuum bagging method is chosen as the primary production technique in this study because it can reduce manufacturing process time and its ability to produce composite structures with high quality and good control over resin distribution [5]. By understanding the relationship between variations in PVC foam core thickness and the bending strength of sandwich composites [6]. The development of composite materials can be optimized for specific applications, contributing positively to product efficiency and performance.

Vacuum bagging is an improvement over the Hand Lay-up method. The process of using vacuum aims to remove trapped and excess air when using resin. In this process, a vacuum pump is used to pull air out from the container where the composite material is placed for molding. By creating a vacuum pressure inside the container, air previously trapped outside the plastic cover will be forced inward. As a result, trapped air within the composite specimen can be minimized [7].

Several researchers have conducted various studies in the field of carbon composites, but few have investigated the “Effect of PVC foam core thickness variations on the Bending Characteristics of Vacuum Bagging Sandwich Composite Foam”. This research is expected to provide deeper insights into the mechanical characteristics of sandwich composites with PVC foam core and serve as a foundation for the development of superior composite materials. Therefore, this study is anticipated to make a significant contribution to advancing knowledge in the field of composite materials and their applications in modern industries.

2. METHOD

The materials used in this sandwich composite study are PVC foam board With a density of 0.7 g/cm³ [3] and thicknesses of 2 mm, 3 mm, 5 mm, 8 mm, and 10 mm, carbon fiber in twill weave pattern with a grammage of 240 gsm and thread density of 6 threads/cm, using Yukalac C-108B resin matrix and Mepoxe catalyst as hardening agent in a ratio of 100:1 grams. The sandwich composite fabrication method employs vacuum bagging with a maximum pressure of 14 Psi.

The equipment needed for manufacturing sandwich composites using vacuum bagging method includes a vacuum bagging machine, glass as the molding base, vacuum bag plastic, breather bleeder, mold release wax, peel ply fabric, release film plastic, angle grinder, and Universal Testing Machine for bending tests, such as the Zwick Roell All Round Z250SR.

The procedure for making sandwich composites is as follows: first, prepare the tools and materials. Second, mix the resin and catalyst in a ratio of 100 grams. Third, apply the matrix on each layer of the sandwich composite: two bottom skin layers, core, and two top skin layers evenly. Fourth, place additional materials on the top layer of the sandwich composite, starting with release film plastic followed by peel ply fabric, breather bleeder, and finally cover with vacuum bag plastic sealed to the glass base using sealant tape. Fifth, remove trapped air by vacuuming using a vacuum bagging machine until reaching a maximum pressure of 14 Psi. Sixth, allow the mold to cure for 24 hours at room temperature, then conduct bending tests using the Zwick Roell All Round Z250SR Universal Testing Machine. This will be clearer after seeing Figure 1.

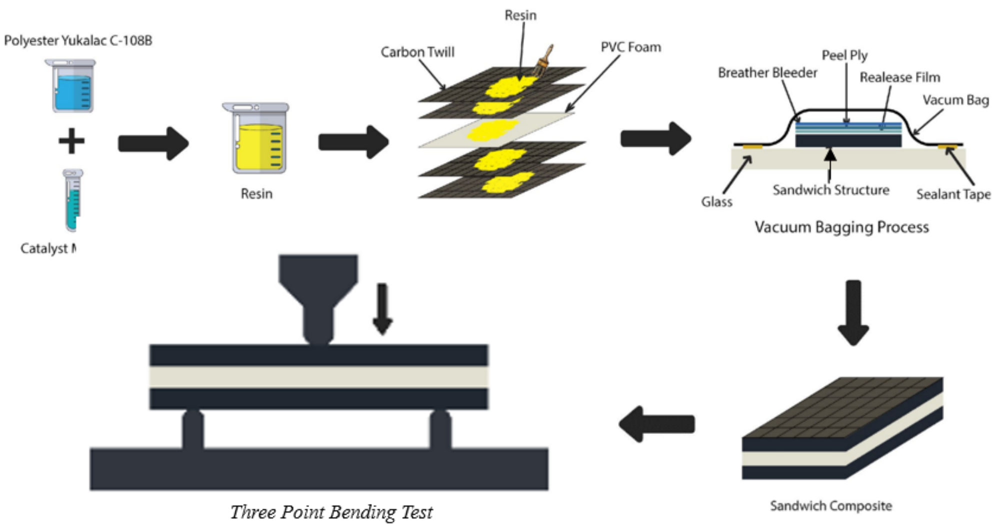


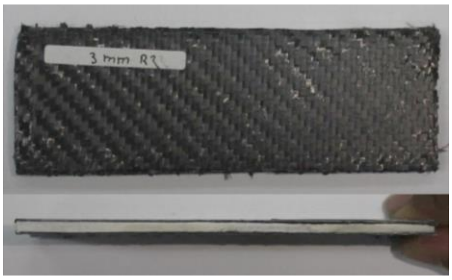
Figure 1. Sandwich Composite Manufacturing Procedure

3. RESULTS AND DISCUSSION

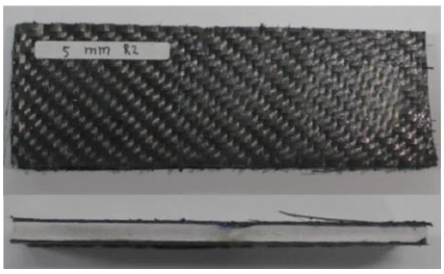
The aim of this research is to explore the maximum bending strength and analyze the fracture results from sandwich composite testing. The results of sandwich composite fabrication and various core thickness variations can be seen in Figure 2, while the data processing results from bending tests and weight can be found in Table 1. Furthermore, the graph depicting the maximum bending strength of sandwich composites with core thickness variations of 2 mm, 3 mm, 5 mm, 8 mm, and 10 mm is shown in Figure 3.

Figure 2 depicts sandwich composites with core thickness variations of 2 mm, 3 mm, 5 mm, 8 mm, and 10 mm. The surface of these sandwich composite specimens appears smooth and glossy due to even resin distribution along the skins during the vacuum bagging process. The composite sandwich thickness dimensions are 3 mm for the 2 mm core thickness variation, 4 mm for the 3 mm core thickness variation, 6 mm for the 5 mm core thickness variation, 9 mm for the 8 mm core thickness variation, and 11 mm for the 10 mm core thickness variation. The sandwich composite thickness increases by 1 mm for each variation due to the addition of two layers of top and bottom skins with additional matrix processed using vacuum bagging method. Figure 2 can also show that the resin is absorbed on the surface of the core so that it can increase the stiffness of the composite [5]. On the other hand, the weight of the composite increases with the increase in core thickness. This can be seen in Table 1.

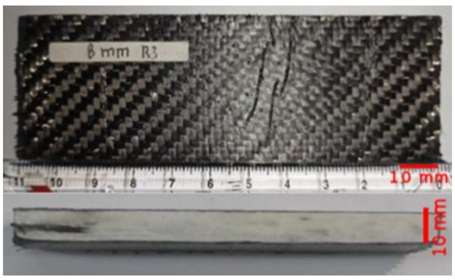
(a) Core Thickness 2 mm



(b) Core Thickness 3 mm



(c) Core Thickness 5 mm



(d) Core Thickness 8 mm

Figure 2. Specimens of Sandwich Composite Fabrication Results with Variations of The Core Thickness: (a) 2 mm, (b) 3 mm, (c) 5 mm, (d) 8 mm

(e) Core Thickness 10 mm

Figure 2. Specimens of Sandwich Composite Fabrication Results with Variations of The Core Thickness 10 mm, continued

Table 1. Bending Test Data Processing Results

No	Variations	Highest bending strength (MPa)				Weight (Grams)			
		R-1	R-2	R-3	Average	R-1	R-2	R-3	Average
1.	Core thickness (2 mm)	97.15	77.16	69.70	81.34	35.55	35.01	34.98	35.18
2.	Core thickness (3 mm)	54.44	62.48	50.46	55.79	53.40	52.78	53.87	53.35
3.	Core thickness (5 mm)	19.02	19.77	11.48	16.76	89.14	89.10	88.98	89.07
4.	Core thickness (8 mm)	15.47	12.56	11.39	13.14	142.40	143.18	142.77	142.78
5.	Core thickness (10 mm)	11.92	13.245	14.08	13.08	178.07	178.16	178.49	178.24

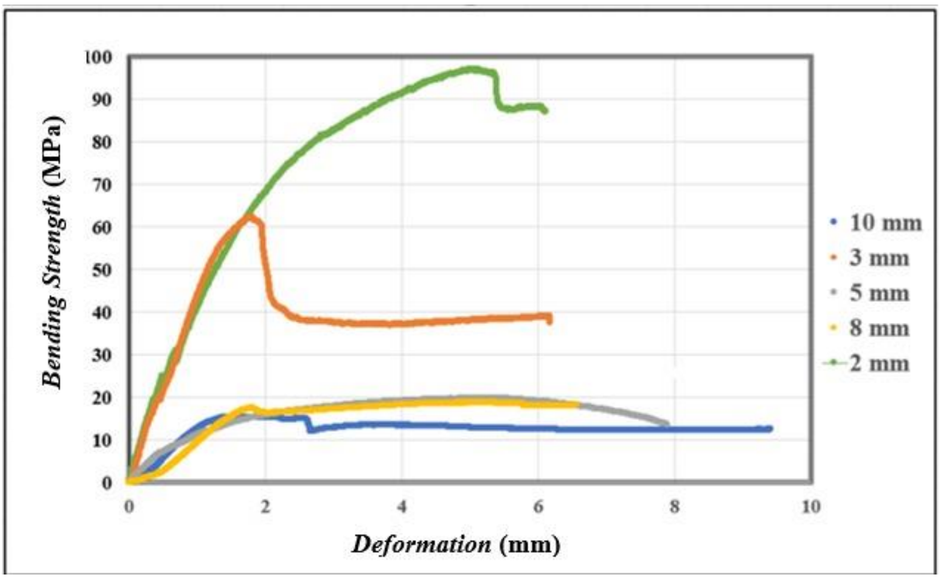


Figure 3. Graph of Maximum Bending Strength Against Core Thickness Variations

Figure 3 shows a graph of the bending test results of sandwich composites, displaying the maximum bending strength values (in MPa). The maximum bending strength value was obtained by the 2 mm core thickness variation at 81.3 MPa, while the lowest value was found with the 10 mm core thickness variation at 13.08 MPa. Bending strength refers to a material's ability to withstand bending stress without significant deformation or failure. It is influenced by the type of material and the magnitude of the load applied to it [7]. The bending strength of sandwich composites is primarily determined by the thickness of its skins. Thicker cores increase the distance between the two skins, affecting skin strength. A 2 mm thick core exhibits the highest strength because both skins work together to withstand bending loads. Conversely, a 10 mm core makes the top skin more susceptible to compression damage, while the bottom skin is more vulnerable to tensile stresses after passing through the thicker core. Additionally, bending stress decreases due to the larger dimensions of the sandwich composite. As the core thickness increases, the sandwich dimensions enlarge, increasing the moment of inertia based on the Equation 1.

$$\frac{1}{12} b.h^3 \quad (1)$$

where
b = The sandwich width
h = The sandwich thickness

The larger the value of h for the core, the greater its influence on the moment of inertia, leading to a decrease in bending stress (strength) according to the basic formula in Equation 2,

$$\sigma = \frac{M.c}{I} \quad (2)$$

where
I = The moment of inertia [8][9][10]

In the bending test results conducted on sandwich composites with core thickness variations of 2 mm, 3 mm, 5 mm, 8 mm, and 10 mm, the number of failures observed were documented. These failures indicate several causes and the forms of failure encountered. Each failure scenario will be illustrated in respective images starting from image a, depicting the initial position of the bending test, image b showing the ongoing bending test, and image c displaying the final position after the bending test. Therefore, the testing and failures can be observed in Figures 4, 5, 6, 7, and 8.

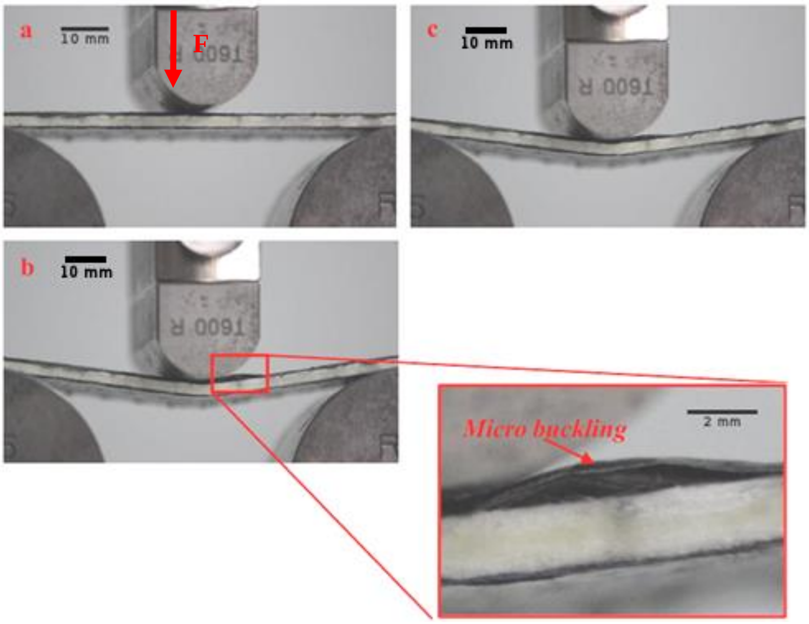


Figure 4. Bending Test of Sandwich Composite with 2 mm Core Thickness Variation

Figure 4 shows the bending test process of the 2 mm core thickness variation of sandwich composite. In figure 4.a, the bending testing process begins on the sandwich composite. The failure process of the sandwich composite occurs gradually, as observed in figure 4.b. The failure phenomenon in the sandwich composite is caused by micro buckling, where the carbon fiber-based skin layer detaches from the PVC foam core. This event happens because the carbon fiber layer is thinner compared to the PVC foam.

After the bending test, the sandwich composite with a 2 mm core thickness achieves a maximum bending strength of 81.34 MPa and an elastic modulus of 32.91 GPa. Maximum bending strength can be caused by thin core material. Absorption of resin to the core surface can increase the stiffness and strength of the composite material[5]. This can be seen in Figure 4 where the resin is seen seeping into the core. Image 4 displays the results of the three-point bending test of the 2 mm core thickness sandwich composite. The test results indicate several failures in this sandwich composite, particularly in the form of micro buckling on the skin. Micro buckling is local failure that occurs on the face sheet or core of a sandwich composite structure due to compressive loads that exceed the material stability limit. Micro buckling begins with fiber instability which causes the fiber to bend locally. The initial damage is usually visible on the compression side of the face sheet in the form of small waves or wrinkles[11][12].

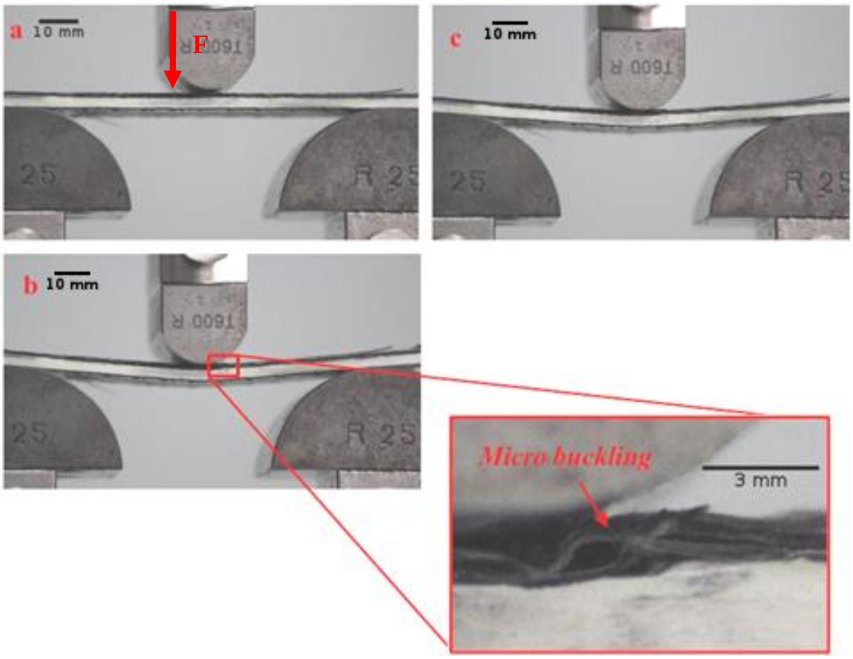


Figure 5. Bending Test of Sandwich Composite with 3 mm Core Thickness Variation

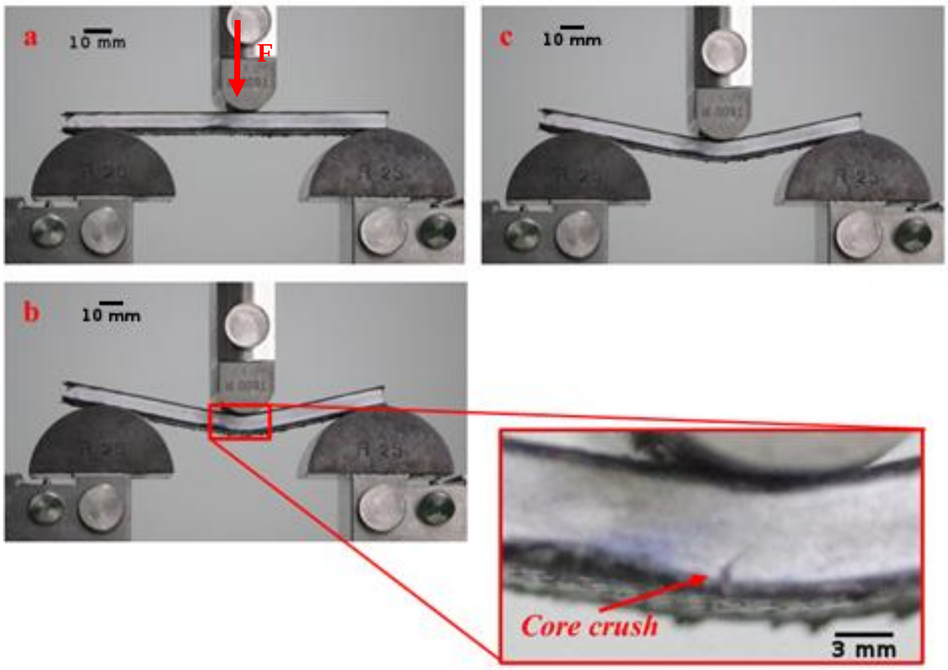


Figure 6. Bending Test of Sandwich Composite with 5 mm Core Thickness Variation

Figure 5 depicts the bending test process of the 3 mm core thickness variation of sandwich composite. In figure 5.a, the sandwich composite is seen under load during the bending test. Deformation changes and failures start to appear in figure 5.b, where micro buckling phenomenon occurs. Micro buckling happens when the carbon fiber-based skin layer detaches from the PVC foam core in the sandwich composite. This is due to the relatively thinner thickness of the carbon fibers compared to the PVC foam [13][4]. Then in figure (c), it shows the sandwich composite after the bending test is completed.

After the bending test, the sandwich composite with a 3 mm core thickness achieves a maximum bending strength of 55.79 MPa and an elastic modulus of 27.92 GPa. Figure 5 displays the results of the three-point bending test of the sandwich composite with a 3 mm core. The test results indicate failures, particularly in the form of micro buckling in this sandwich composite.

Figure 6 illustrates the bending test process of the sandwich composite with a 5 mm core thickness variation. In figure 6.a, the sandwich composite is seen under load during the bending test. Deformation changes and failures start to appear in figure 6.b, where core crush failure occurs. Core crush happens when cracks and damage occur in the sandwich composite core due to applied load [37]. Figure 6.c shows that the bending test process has been completed on this sandwich composite.

After the bending test, the sandwich composite with a 5 mm core thickness achieves a maximum bending strength of 16.76 MPa and an elastic modulus of 0.00067 GPa. Figure 6 displays the results of the three-point bending test of the sandwich composite with a 5 mm core after completion. After the bending test, failures are evident in the sandwich composite with a 5 mm core thickness. Upon closer inspection in the post-bending test images, cracks or failures are not prominently visible, but careful observation reveals that the failure mode is core crush. Core crush is a type of failure where cracks and damage occur in the sandwich composite core due to the applied load [14].

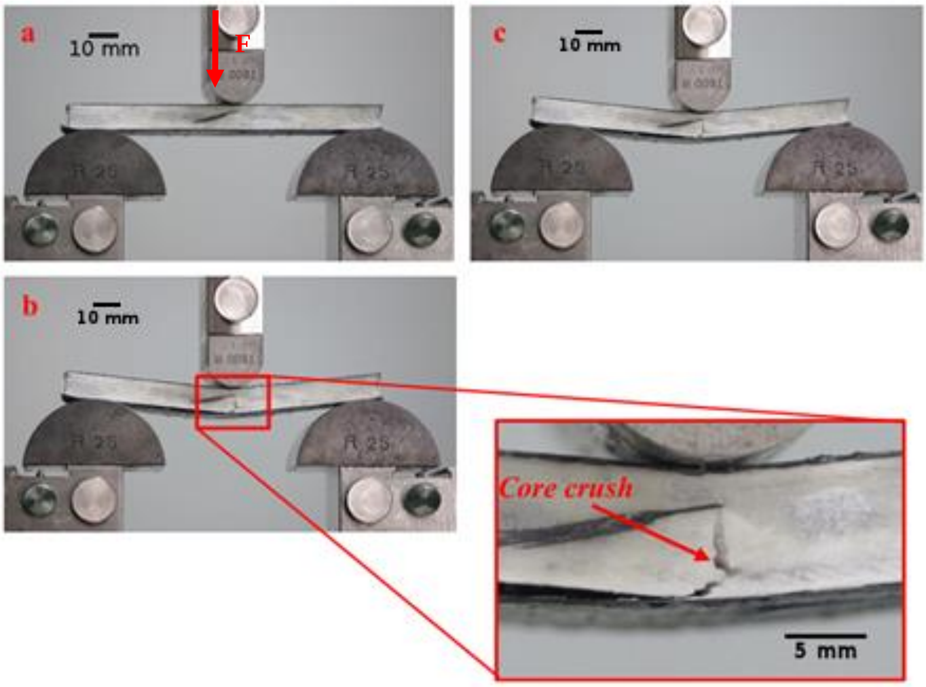


Figure 7. Bending Test of Sandwich Composite with 8 mm Core Thickness Variation

Figure 7 depicts the bending test process of the sandwich composite with an 8 mm core thickness variation. In figure 7.a, the sandwich composite is observed under load during the bending test. Deformation changes and failures start to appear in figure 7.b, where core crush failure occurs. Core crush is a type of structural failure that occurs in the core material of a sandwich composite when the core experiences permanent deformation, local failure, or crushing due to high pressure or other mechanical forces. Core crush often occurs in compression, shear, or flexure tests, where the core is subjected to a load that exceeds its bearing capacity[15]. Core crush is a type of failure where cracks and damage occur in the sandwich composite core due to the applied load [14]. Subsequently, figure (c) shows the sandwich composite after the bending test has been conducted.

After the bending test, the sandwich composite with an 8 mm core thickness achieves a maximum bending strength of 13.14 MPa and an elastic modulus of 0.00017 GPa. Figure 7 displays the results of the three-point bending test of the sandwich composite with an 8 mm core after completion. Failures are observed in the sandwich composite with an 8 mm core thickness after the bending test. Upon taking images after the bending test, cracks or failures are not very visible, but careful examination reveals that the failure mode is core crush.

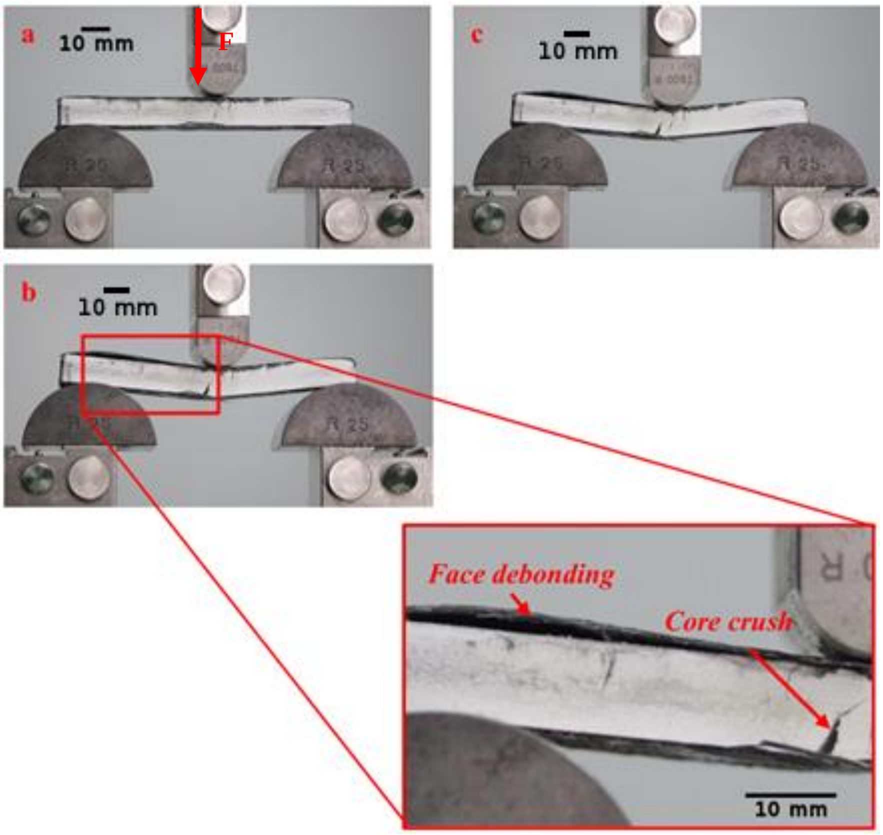


Figure 8. Bending Test of Sandwich Composite with 10 mm Core Thickness Variation

Figure 8 illustrates the bending test process of the sandwich composite with a 10 mm core thickness variation. In figure 8.a, the sandwich composite is seen under load during the bending test. Deformation changes and failures start to appear in figure 8.b, where face debonding failure occurs. Face debonding is a failure phenomenon where separation occurs between the skin and core in the sandwich composite. This condition occurs when there is a separation between the core and skin layers in the sandwich composite. This delamination indicates that the low core strength results in the interface being unable to withstand shear loads.

Figure 8.c depicts an increasing micro buckling failure. At the same time, a new failure occurs in the sandwich composite core known as core crush. Core crush occurs when the sandwich composite specimen cracks and the core is crushed under load. In the image, cracks in the core are enlarging, while face debonding failure does not significantly expand.

After the bending test, it was found that the sandwich composite with a 10 mm core thickness achieves a maximum bending strength of 13.08 MPa and an elastic modulus of 0.00015 GPa. Image 8 shows the sandwich composite after undergoing the three-point bending test. The results indicate failures in the sandwich composite with a 10 mm core thickness, including face debonding and core crush. Face debonding occurs due to delamination between the core and skin layers, while core crush results from cracking and crushing of the core composite under load [16].

The most common failure observed in the bending test results of sandwich composites with core thickness variations of 2 mm, 3 mm, 5 mm, 8 mm, and 10 mm is micro buckling, a phenomenon where thin layers or material structures experience local bending or fracturing on a microscopic scale. This type of failure occurred in three core thickness variations: 2 mm and 3 mm. Micro buckling can be attributed to the relatively thinner carbon fibers compared to PVC foam [14]. For the 5 mm, 8 mm, and 10 mm core thickness variations, another type of failure observed is core crush, which involves cracking and crushing of the composite core under load [15][3]In the case of the 10 mm core thickness variation, there were two simultaneous failures: core crush and face debonding. Based on data processing and observation of cracks or failures in the sandwich composites tested, micro buckling was found in the 2 mm and 3 mm core thickness variations, which did not significantly affect the bending strength. The bending strength results for these variations were 81.3 MPa and 55.79 MPa, respectively. However, core crush had a significant impact on bending strength, as observed in the 5 mm, 8 mm, and 10 mm core thickness variations. These variations exhibited maximum bending strengths of 16.76 MPa, 13.14 MPa, and 13.08 MPa, respectively, indicating failure due to core crush.

4. CONCLUSION

From the research results, testing analysis, and discussions obtained, it can be concluded that the sandwich composite exhibits the highest bending strength at a 2 mm core thickness variation, reaching 81.34 MPa, while the lowest bending strength is recorded at a 10 mm core thickness variation, which is 13.08 MPa. From these results, it can be inferred that as the core thickness increases in the sandwich composite, the bending strength decreases. This occurs due to differences in core dimensions that cause the top and bottom skins of the sandwich composite to experience stress differently. This is influenced by the moment of inertia from the bending stress formula.

Failures observed in the sandwich composite after conducting the three-point bending test include core failures such as micro buckling in the 2 mm and 3 mm core thickness variations. Skin failures like micro buckling occurred in the 5 mm and 8 mm core thickness variations. A skin failure in the form of face debonding occurred in the 10 mm core thickness variation.

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