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EFFECT OF WOOD GRAIN ORIENTATION ON BENDING AND IMPACT STRENGTH OF CARBON FIBER–BALSA COMPOSITES

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Abstract

Wood grain orientation significantly influences the mechanical performance of sandwich composites. This study evaluates the effect of balsa wood grain orientation (0°, 30°, 60°, and 90°) as a core material on the flexural and impact strength of carbon fibre–balsa wood sandwich composites with a polyester resin matrix. Composites were fabricated using the vacuum bagging method. Three-point bending tests (ASTM C393) and drop weight impact tests (ASTM D7136) were conducted. The results showed that the straight grain orientation (0°) produced the highest flexural strength of 22.77 MPa and the best impact resistance. In contrast, the 90° orientation gave the lowest flexural strength (9.39 MPa) due to load being sustained primarily by the matrix. Failure analysis revealed debonding, face wrinkling, core shear, and fibre breakage. It is concluded that balsa wood grain orientation significantly affects mechanical performance, with the 0° orientation being optimal for lightweight structural applications.

Key words: Sandwich Composite, Balsa Wood Fiber, Bending, Drop Weight Impact, Vacuum Bagging

INTRODUCTION

The development of the manufacturing industry inseparable from the field of engineering which directly with materials science. Generally materials are classified into two main categories metals and non-metals. Non-metals are materials that contain little to no iron elements and are frequently utilized due to unique properties that metallic materials lack. Non-metallic materials can be categorized into three groups: ceramics, plastics and composites (M.Rintami, 2022).

A composite is a material formed from a combination of two or more distinct materials. Its constituents consist of a matrix, which acts as a binder and reinforcement, which provides strength. Composite materials offer several advantages, including low density, corrosion resistance and the ability to tailor material characteristics to specific requirements. Due to these superior properties and specialized characteristics, various types have been developed of which the sandwich composite (C.S.Evi, 2008).

A sandwich composite is a type of composite structure consisting of at least three layers: the upper and lower surfaces known as skins and a core material situated in the middle. Sandwich composites are specifically engineered to achieve optimal weight efficiency while maintaining high structural strength (N.Sari, 2014). Along with advancements in materials science and technology there is an increasing demand for materials that are both advanced and environmentally friendly Consequently, sandwich composite materials utilizing natural fibers as cores have been frequently developed; for instance, the aerospace industry utilizes balsa wood as a structural core to reduce aircraft weight (Reza Adhan, 2014).

Balsa wood is renowned for its low density and high specific strength. In addition to its lightweight nature, ease of cutting, and formability balsa wood also possesses excellent absorption capabilities. In current industrial developments balsa wood is frequently utilized as a core material in sandwich composites for aircraft wings, wind turbine blades, and various automotive components (Tüfekci, 2023).

Research conducted by Sri Hastuti et 2022 regarding the influence of grain orientation variations on the characteristics of composites with albizzia falcataria wood cores obtained flexural strength value of 178.03 N/mm² at a 0/90° orientation. From these results, it can be concluded the grain orientation significantly affects material characteristics. Consequently similar research must be conducted on balsa wood grain orientations to produce an optimized sandwich composite that meets specific requirements (Sri Hastuti, 2022).

Based on the aforementioned background, it can be concluded that modern manufacturing industries are highly dependent non-metallic materials. Natural materials such as balsa wood are effectively utilized as polymer reinforcements offering environmentally friendly alternatives with superior strength and durability, as well as wide applications ranging from industrial uses to consumer products. Therefore, further research is required to investigate the effect of variations in wood grain orientation on the bending and impact strength of carbon fiber sandwich composites with balsa wood cores. This is essential to understand their characteristics as a basis for developing more advanced composite materials.

METHODS

The materials utilized in this research include balsa wood (*ochroma pyramidale*), carbon fiber, and polyester resin. The skin material consists of 3K 240 Gsm twill weave carbon fiber. The balsa wood core dimensions are 10x30x100 mm for the bending test and 05x100x150 mm for the drop weight impact test. The matrix system employed is yukalac C-108B polyester resin, combined with mepoxe catalyst as a hardener at a mixing ratio of 10:1. The sandwich composites were fabricated using the vacuum bagging method at a pressure of 14 Psi under room temperature.

The composite fabrication process was carried out using the vacuum bagging method to ensure uniform resin distribution and minimize defects. The resulting specimens were then sectioned according to standardized testing ASTM C393 for the three point bending test and ASTM D7136 for the drop weight impact test Both bending and impact test were conducted to determine the mechanical strength and evaluate impact induced damage characteristics based on the balsa wood grain orientations (0°, 30°, 60°, and 90°)

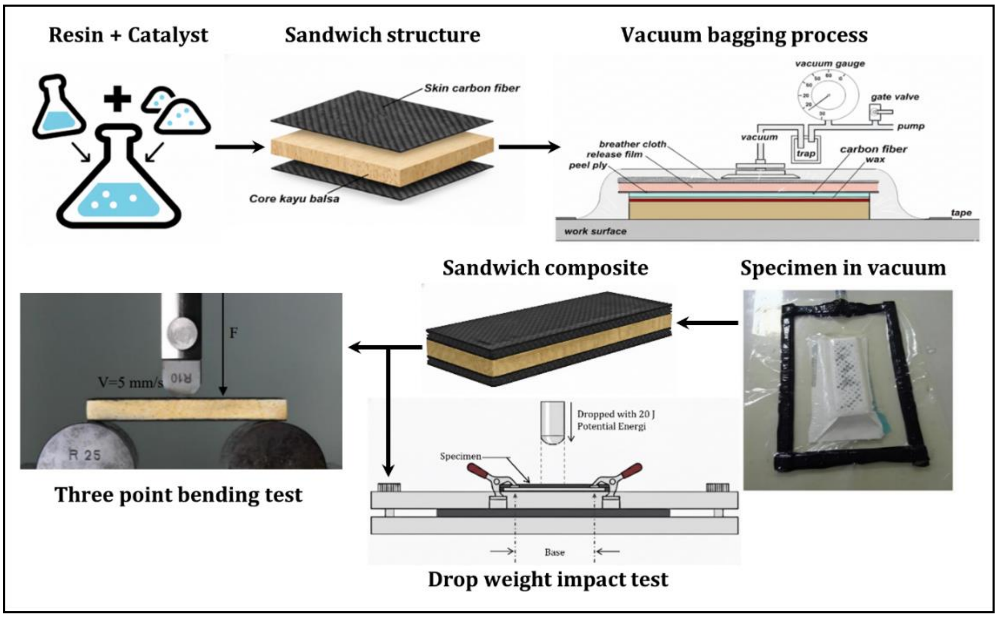


Figure 1. Composite Manufacturing Process

Figure 1 illustrates the fabrication process of the sandwich composite using the vacuum bagging method, where the composite materials are consolidated within the mold by utilizing uniform atmospheric pressure (R.Bahadjai, 2017). Following the fabrication process, the specimens underwent three point bending testing using a Zwick Roell Z250SR Universal Testing Machine (UTM) at a loading rate of 5 mm/s. Additionally the drop weight impact test was conducted with a potential energy of 20 Joules.

The maximum flexural strength obtained from the three point bending test method can be determined using the following equation:

$$\sigma_f = \frac{3\,PL}{2\,bh^2} \quad \text{.................................} \ (1)$$

Information:

σ_f = Flexural strength (MPa)

P = Maximum load (N)
L = Support span (mm)
b = Specimen width (mm)
h = Specimen thickness (mm)

Potential energy on the other hand is the energy possessed by an object due to its position or elevation. Every object possesses gravitational potential energy, which can perform work when the object is in motion. The value of this energy can be determined using the following equation:

$$E_p = m.\,g.\,h \quad \text{...........................} \ (2)$$

Information:

E_p = Potential energy (J)
m = Mass of the impactor (kg)
g = Gravitational acceleration (9,81 m/s^2)
h = Drop height (m)

RESULTS AND DISCUSSION

This study aims to determine the maximum flexural strength of carbon fiber sandwich composites with balsa wood cores under various grain orientations In addition, an analysis of the failure mechanism that flexural loading is conducted to understand the structural response of the composites. The prepared test specimens are presented in figure 2 below.

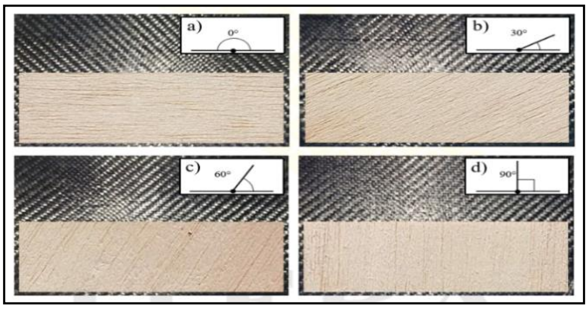


Figure 2. Specimen of Composite

Figure 2 shows the fabricated carbon fiber sandwich composites with balsa wood cores and a polyester matrix across various wood grain orientations. The figure demonstrates the physical differences visible to the naked eye. These distinctions are clearly observable in the alignment of the balsa wood grain orientations.

A. Three Point Bending

The bending tests were conducted in accordance with the ASTM C393 standard, which is specifically established to explore the maximum flexural strength and failure mechanisms of sandwich structures. The experiments involved testing four variations of wood grain orientations each consisting of three composite specimens to ensure data reliability and obtain average values as presented in the following table:

Table 1. Bending test

No.	Orientation	Maximum flexural strength			
		R1	R2	R3	x̄
1.	0°	19.15	12.92	36.24	22.77
2.	30°	14.88	23.19	17.33	18.47
3.	60°	11.39	8.66	8.89	9.65
4.	90°	8.93	10.46	8.78	9.39

Table 1 and figure 3 presents the data from the three point bending tests on carbon fiber sandwich composites, specifically the flexural strength values Flexural strength represents the maximum stress a material can withstand under external loading before failure occurs. This strength value is influenced by the type of materials used and the loading characteristics (Dadang Setiyawan, 2020) As a result of the bending test, the upper part of the specimen undergoes compression, while the lower part experiences tension.

The grain orientation of the balsa wood used as the core in carbon fiber sandwich composites significantly influences the resulting stress values. The maximum average flexural strength was obtained from the straight grain orientation (0°) reaching 22.77 MPa. Conversely the lowest value was recorded in the perpendicular grain orientation (90°) which was 9.39 MPa. The graph illustrating the maximum flexural strength of the carbon fiber sandwich composites relative to the balsa wood grain orientation variations can be seen in the following figure.

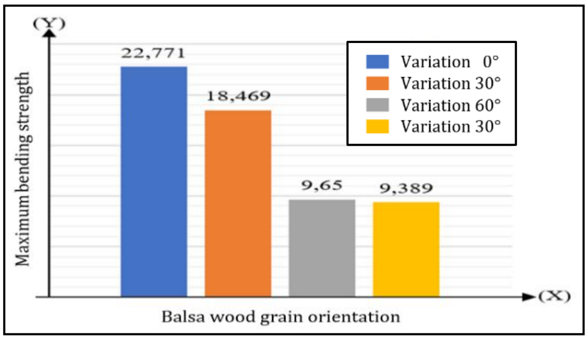


Figure 3. Bending Strength Graph

Balsa wood exhibits its highest flexural strength at the 0° grain orientation because the fibers are aligned parallel to the loading direction In this condition, the wood fibers can optimally withstand bending forces as the load is distributed along the grain length. Conversely when the grain orientations are angled (30° = 18.47 MPa; 60° = 9.65 MPa; 90° = 9.39 MPa) the strength is weaker and tends to decrease significantly. This is caused by the reduced capability of the fibers to resist the applied load (Astasari, 2017).

The 90° grain orientation is positioned perpendicular to the direction of the applied force causing the load to be predominantly sustained by the matrix. Consequently the material's ability to withstand bending loads decreases significantly. This phenomenon reflects the anisotropic nature of balsa wood, where the grain direction profoundly influences its mechanical behavior. Therefore, grain orientation plays a crucial role in determining the maximum flexural strength achievable by the overall material (Agus Dani, 2024). The following graph illustrates the maximum flexural strength for specimen variation

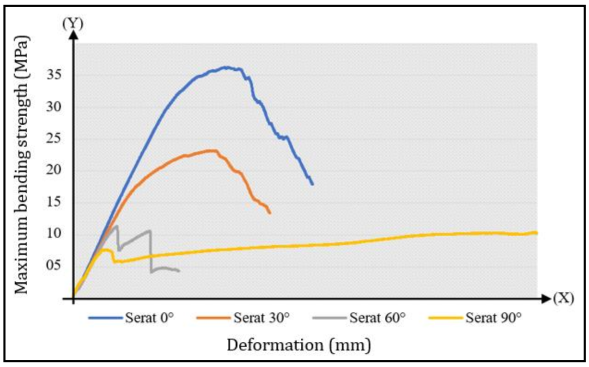


Figure 4. Maximum Bending Strength Graph

Figure 4 illustrates the peak flexural strength achieved by each variation. The highest value was obtained by the 0° straight grain orientation at 36.24 MPa, while the 30° orientation reached 23.19 MPa followed by the 60° orientation at 11.39 MPa, and the 90° orientation at 10.46 MPa. Based on the tested material samples several failure phases were identified: the linear deformation stage plastic deformation stage, fracture stage, and failure stage (Zichen Zhang, 2023).

The linear deformation stage is defined by the yield strain area, which is the zone when the specimen is initially subjected to loading. The plastic deformation stage is characterized by the peak strain area, where the test specimen reaches its maximum strain limit. The fracture stage refers to the phase where macro cracks begin to emerge. Finally, the failure stage occurs when the specimen undergoes total structural damage and is no longer capable of sustaining the applied load. Flexural strength is defined as the maximum bending stress a material can withstand under external loading without experiencing significant structural failure (Rizky Saputra, 2024).

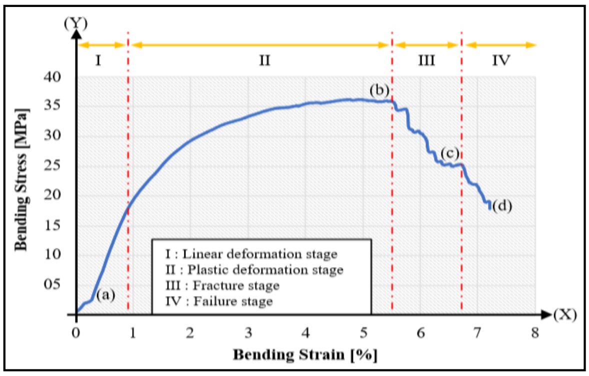


Figure 5. Maximum bending variation graph (0°)

Figure 5 presents the maximum flexural strength graph of the sandwich composite with a (0°) grain orientation. This graph visualizes the failure phases of the composite material during the testing process. Zone (I) is identified as the linear deformation stage, representing the initial condition when the specimen is subjected to loading. The beginning of the curve shows an increase in flexural stress that nearly forms a straight line within the 0.5–0.9% strain range reaching a peak value of 17.07 MPa. If the loading is discontinued during this phase, the specimen returns to its original shape without permanent deformation. During this stage the material experiences initial debonding, which is the adhesive separation between different material layers as observed at point (a). Subsequently, the test proceeded at a constant loading rate of 5 mm/s

Zone (II) is identified the plastic deformation stage which is the region where the specimen reaches its maximum strain limit. After surpassing the elastic limit the curve begins to bend, indicating that the material is undergoing permanent deformation. The peak of the curve, within the 4.5–5.5% strain range with a maximum value of 36.24 MPa, represents the ultimate flexural strength the specimen can withstand before experiencing a significant drop in load bearing capacity. Within this zone, the specimen undergoes face wrinkling failure a localized buckling or wrinkling of the carbon fiber skin layers at a load of 1,034.99 N (G.Epasto, 2024)

Zone (III) is referred to as the fracture stage the phase where the specimen begins to experience failure in the balsa wood core. After reaching the curve's peak, a significant drop in flexural stress is observed indicating that massive internal damage has occurred. In the 5.5–6.8% strain range a fluctuating (wave-like) decrease is visible on the curve suggesting that the failure is progressing gradually. The specific failure identified is debonding at a load of 729.46 N, with a flexural stress value of 25.33 MPa in figure 6 below

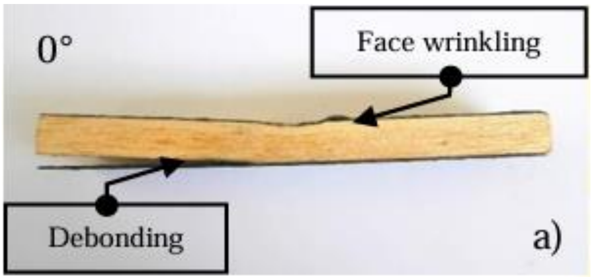


Figure 6. Bonding Failure on specimen variation (0°)

Zone (IV) is the failure stage, where the specimen undergoes total structural collapse Starting from the 6.8–7.2% strain range the flexural stress values continue to decline toward zero signifying that the specimen is no longer capable of sustaining the applied bending loads.

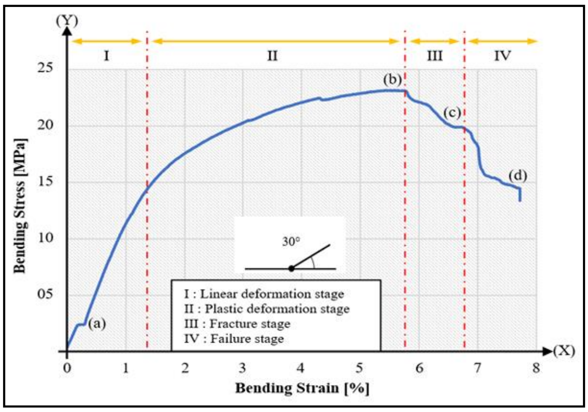


Figure 7. Maximum bending variation graph (30°)

Figure 7 illustrates the maximum flexural strength graph of the sandwich composite with a 30° grain orientation. This graph visualizes the failure phases of the composite material throughout the testing process. In Zone (I) the initial part of the curve shows an increase in flexural stress within the 0.3–1.3% strain range, reaching a peak value of 14.14 MPa. During this phase, the material experiences initial debonding at point (a).

In Zone (II) after surpassing the elastic limit the curve begins to bend, indicating that material is undergoing permanent deformation. The flexural load continues to increase until it reaches the 5.5–5.8% strain range, with a value of 23.19 MPa which represents the ultimate flexural strength of the material. Within this zone the specimen experiences debonding failure at a load of 667.86 N. Debonding is defined as the partial loss of interfacial adhesion between the carbon fiber skin and the balsa wood core (S.Shah, 2023).

In Zone (III) after reaching the peak of the curve a significant drop in flexural stress is observed. This indicates the occurrence of core shear failure at a load of 568.78 N with a flexural stress value of 19.75 MPa, this failure in figure 6

Zone (IV) is the failure stage, where the specimen undergoes total structural collapse Starting from the 6.8–7.8% strain range, the flexural stress values continue to decline toward zero indicating that the specimen has completely lost its load-bearing capacity.

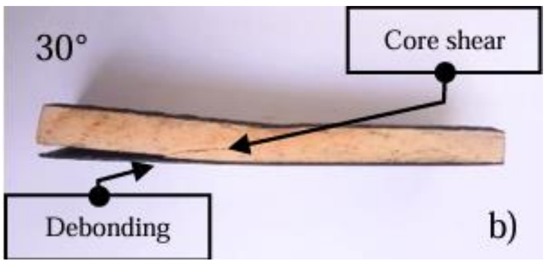


Figure 8. Bonding failure on specimen variation (30°)

Figure 8 shows the failure modes observed in the sandwich composite with a 30° balsa wood grain orientation after three-point bending testing. Two primary failure mechanisms are identified: debonding and core shear.

Debonding is clearly visible at the interface between the carbon fibre skin and the balsa wood core. This failure occurs when the adhesive bond between the skin and core is insufficient to withstand the shear stresses generated during bending. As the bending load increases, the difference in stiffness between the carbon fibre skin (high stiffness) and the balsa wood core (low stiffness) creates significant interfacial shear stress. Once this stress exceeds the interfacial strength, debonding initiates and propagates along the interface. This finding is consistent with observations by Shah et al. [13], who reported that debonding is the dominant failure mode in sandwich composites with angled core materials.

Core shear is also evident in Figure 8, indicated by a diagonal crack propagating through the thickness of the balsa wood core. Core shear failure occurs when the transverse shear stress within the core exceeds the shear strength of the balsa wood. At a 30° grain orientation, the wood fibres are neither fully aligned with nor perpendicular to the loading direction, resulting in a combination of compressive, tensile, and shear stresses within the core. The core shear failure in this specimen was recorded at a load of 568.78 N with a flexural stress value of 19.75 MPa. This failure mode is critical because once the core loses its shear resistance, the sandwich structure can no longer transfer load effectively between the two skins, leading to a sudden drop in load-bearing capacity.

The interaction between debonding and core shear is particularly important. In the 30° orientation, debonding typically precedes core shear. The initial loss of skin-core adhesion reduces the composite's ability to distribute bending moments, thereby concentrating shear stresses in a smaller region of the core. This stress concentration accelerates core shear failure. Consequently, the 30° orientation exhibits a lower flexural strength (18.47 MPa on average) compared to the 0° orientation (22.77 MPa), but still performs better than the 60° and 90° orientations. These results confirm that even a moderate change in grain orientation (from 0° to 30°) compromises the structural integrity of the sandwich composite by promoting interfacial and internal shear failures.

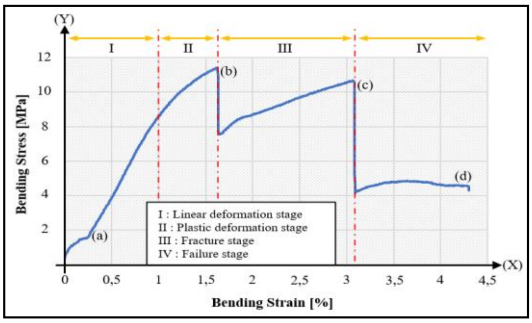


Figure 9. Maximum bending variation graph (60°)

Figure 9 illustrates the maximum flexural strength graph of the sandwich composite with a 60° grain orientation. In Zone (I) the curve exhibits a linear relationship between flexural stress and flexural strain within the 0.3–1% range, reaching a peak value of 8.51 MPa. During this phase, the material undergoes initial debonding at point (a).

In Zone (II) the material continues to sustain an increasing flexural load until it reaches its peak at the 1–1.6% strain range. The value of 11.39 MPa represents the ultimate flexural strength that the specimen can withstand. Subsequently, the material experiences a very steep decline in stress, indicating the occurrence of the first significant failure.

After undergoing significant plastic deformation, the material reaches its second load carrying capacity limit. Zone (III) is referred to as the fracture stage, a phase where the specimen experiences debonding failure and micro-cracking within the balsa wood core, which continues to propagate as the load increases. Following an initial drop to 7.54 MPa, a subsequent increase occurs indicating the material's residual resistance which eventually reaches 10.64 MPa.

In Zone (IV) the specimen undergoes a very sharp and sudden stress drop, which is even steeper than the first decline. This signifies the occurrence of a second, more comprehensive structural failure. The failure begins within the 3.1–4.3% bending strain range, with the flexural stress declining toward zero. A curve flattening is observed indicating that the increase in strain is no longer accompanied by an increase in the structure's strength.

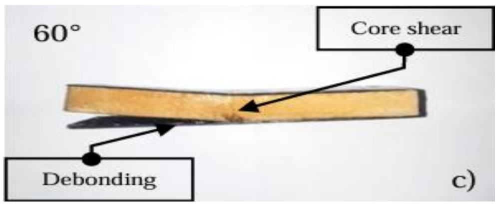


Figure 10. Bonding failure on specimen variation (60°)

Figure 10 presents the failure modes observed in the sandwich composite with a 60° balsa wood grain orientation after three-point bending testing. Two dominant failure mechanisms are identified: debonding and core shear, similar to the 30° orientation, but with more severe characteristics.

Debonding is clearly visible at the interface between the carbon fibre skin and the balsa wood core. At a 60° grain orientation, the wood fibres are oriented further away from the loading direction compared to the 30° specimen. This misalignment reduces the effective load transfer between the skin and core, leading to earlier initiation of interfacial debonding. The debonding observed in Figure 10 appears more extensive than in the 30° case, propagating along a longer section of the interface. This is consistent with the lower flexural strength recorded for the 60° orientation (9.65 MPa on average) compared to the 30° orientation (18.47 MPa). The reduced interfacial adhesion at 60° causes the carbon fibre skin to separate from the core at a lower bending load.

Core shear is also evident in Figure 10, indicated by a distinct diagonal crack propagating through the balsa wood core. At a 60° orientation, the wood fibres are oriented nearly transverse to the applied load, significantly reducing the core's ability to resist shear stresses. The core shear failure in this specimen occurred at a much lower load compared to the 30° orientation. The bending stress-strain curve for the 60° orientation (Figure 9 in the original manuscript) showed a very steep decline after reaching the ultimate flexural strength, indicating that core shear failure is catastrophic once initiated. This behaviour is attributed to the anisotropic nature of balsa wood; at 60°, the fibres offer minimal resistance to transverse shear, causing the core to split along the grain direction.

The combination of debonding and core shear in the 60° orientation leads to a complex failure sequence. Unlike the 30° orientation where debonding preceded core shear, in the 60° specimen both failures occur almost simultaneously. The bending curve for 60° (Figure 9) showed multiple stress drops, indicating progressive damage. After the initial drop, a secondary load-bearing capacity was observed (10.64 MPa), suggesting that the carbon fibre skins temporarily sustained load independently after complete debonding and core shear. However, this residual strength was short-lived, as final failure occurred with a very sharp stress drop.

Compared to the 0° and 30° orientations, the 60° orientation exhibits significantly inferior mechanical performance. The results confirm that as the grain angle increases beyond 30°, the combined effects of debonding and core shear dramatically reduce both flexural strength and structural integrity. Therefore, for applications requiring reliable load-bearing capacity, balsa wood grain orientations above 30° are not recommended.

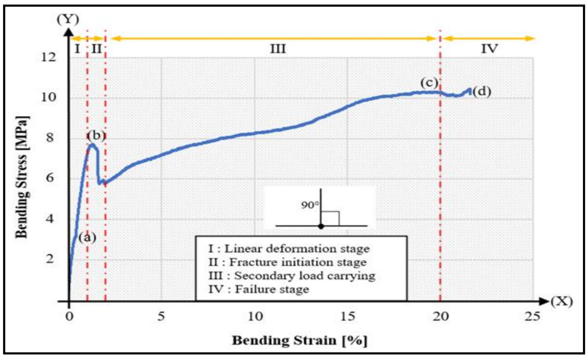


Figure 11. Maximum bending variation graph (90°)

Figure 11 presents the maximum flexural strength graph of the sandwich composite with a 90° grain orientation. In Zone (I) the initial part of the curve shows an increase in flexural stress nearly forming a straight line within the 0–1% strain range, with a peak value of 7.04 MPa. During this phase the material experiences initial debonding at point (a). If the loading is discontinued at this stage the specimen undergoes elastic recovery, returning to its original shape without any permanent deformation.

Zone (II) is referred to as fracture initiation which is the early stage of structural damage within the material. After surpassing the elastic limit, the curve begins to bend indicating that the material is undergoing permanent deformation. The peak of the curve occurs within the 1–2% strain range with a value of 7.56 MPa, followed by a sharp decline to 5.75 MPa. This indicates the first failure where the specimen experiences debonding and micro cracking within the balsa wood fibers. After this decline, the material does not collapse immediately but instead enters the subsequent deformation.

After undergoing significant plastic deformation the material reaches its second load bearing limit in Zone (III) referred to as the secondary load carrying stage. This is a phase where the structure is still capable of sustaining loads despite having experienced initial damage. The curve rises gradually until it reaches a maximum flexural strength of 10.46 MPa within a 2–20% strain range. At this stage the majority of the load is sustained only by the skin layers and the remaining structural remnants of the balsa wood.

Zone (IV) is referred to as the final failure stage. The failure initiates within the 20–22% bending strain range, which marks the secondary peak of the flexural stress values. After reaching this second peak, the curve shows a slight decline signifying the condition where the specimen is no longer capable of significantly sustaining the load. The following figures illustrate the failure modes observed during the three-point bending test for the carbon fiber sandwich composite specimens with a balsa wood core at a 90° grain orientation.

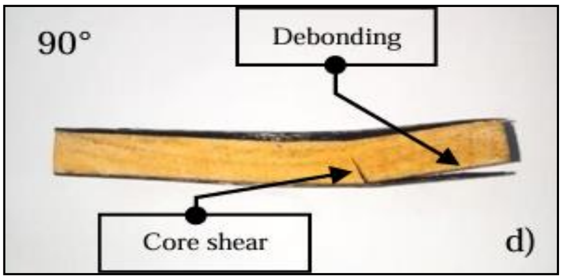


Figure 12. vonding failure on specimen variation (90°)

Figure 12 shows the failure mode of the sandwich composite with a 90° balsa wood grain orientation after three-point bending testing. At this orientation, the wood fibres are perpendicular to the loading direction. The primary failure observed is debonding between the carbon fibre skin and the balsa wood core, accompanied by core micro-cracking and fibre breakage at the bottom skin.

Unlike the 0°, 30°, and 60° orientations, the 90° specimen did not exhibit a distinct core shear crack. Instead, the core failed progressively through multiple small cracks, as seen in the figure. This is because at 90°, the load is almost entirely sustained by the polyester matrix rather than by the wood fibres. The matrix-dominated behaviour results in very low flexural strength (average 9.39 MPa, the lowest among all variations). The bending curve for 90° (Figure 11 in the original manuscript) showed a secondary load peak after initial failure, indicating that the carbon fibre skins temporarily carried the load independently after the core lost its integrity. However, the overall structural performance was poor, making the 90° orientation unsuitable for load-bearing applications.

B. Drop Weight Impact

Impact testing was conducted using a drop weight impact tester at the Mechanical Engineering Fabrication Laboratory, ITERA. Specimen prepared followed the ASTM D7136 standard to characterize the material's behavior when subjected to sudden loading (Z.Karim, 2023). The drop weight impact test is performed by dropping a heavy weight such as a hammer or an impactor, from a specified height onto the test sample (Akbar Reza, 2025). The resulting data consists of a macroscopic analysis of the failure modes in the carbon fiber sandwich composite with a balsa wood core. The results of the drop weight impact test are presented in this table.

Table 2. Impact Test

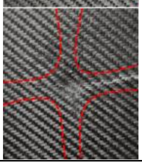
Variations	Potential energy	Damage analysis Top	Bottom
0°	20 joule		
30°	20 joule		
60°	20 joule		
90°	20 joule		

Table 2 presents the data from the drop weight impact tests on the sandwich composite materials, displaying both top and bottom views of the specimens post testing. Impact testing is utilized to measure a material's capacity to withstand impact loads by determining the amount of energy required to fracture the specimen (Kokok Tri Budianto, 2017). A potential energy of 20 Joules was generated using 1.5 kg impactor in a free fall motion from height of 136 cm. The impactor was released precisely at the center of the sandwich composite specimen, resulting in a failure area concentrated in the central region. The following figures illustrate the specimen damage after the testing process.

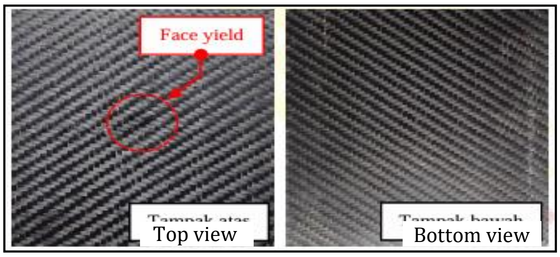


Figure 13. Impact failure at variation (0°)

Figure 13 shows the specimen with a 0° grain orientation variation, which experienced face yield damage. Face yield is a condition where yielding occurs on the skin of a sandwich structure when subjected to an impact load. This failure occurs when the composite's skin layers undergo permanent deformation due to normal stresses that exceed their yield strength.

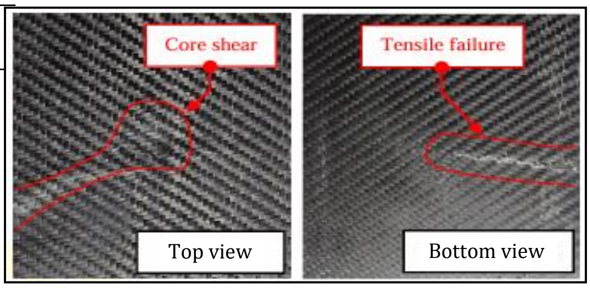


Figure 14. Impact failure at variation (30°)

Figure 14 shows the specimen with a 30° grain orientation variation, which experienced core shear damage, leading to tensile failure at the bottom skin. Tensile failure in composite materials is characterized by fiber breakage and matrix cracking. Scientifically, this occurs because the balsa wood core is no longer capable of sustaining the shear forces causing the tensile load to be fully transferred to the skin. Consequently the bottom skin layer fails with longitudinal cracks propagating parallel to the fiber direction

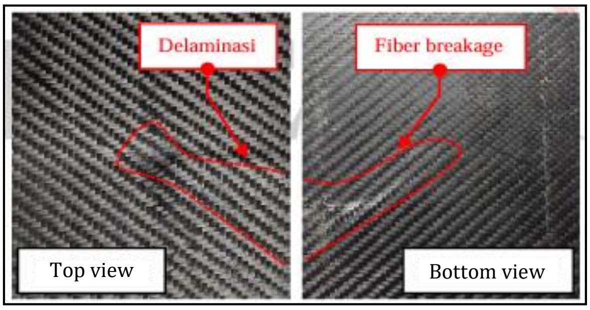


Figure 15. Impact failure at variation (60°)

Figure 15 shows the specimen with a 60° grain orientation variation, which experienced delamination on the top skin layer and fiber breakage at the bottom. Delamination is a failure caused by the inability of the balsa wood core to sustain the load (Fajar Paundra, 2024). Fiber breakage refers to the fracturing of the reinforcing fibers within the composite due to tensile or compressive stresses that exceed the fiber's strength.

Figure 16 illustrates the specimen with a 90° grain orientation, which experienced face wrinkling on the top surface and fiber breakage at the bottom under flexural loading. This condition indicates that the sandwich composite underwent compressive stress on the upper skin and tensile stress on the lower skin, leading to different failure modes within the structure. Face wrinkling is a failure mechanism caused by the structural instability of the outer skin when subjected to high compressive stress, resulting in localized buckling of the sandwich composite surface.

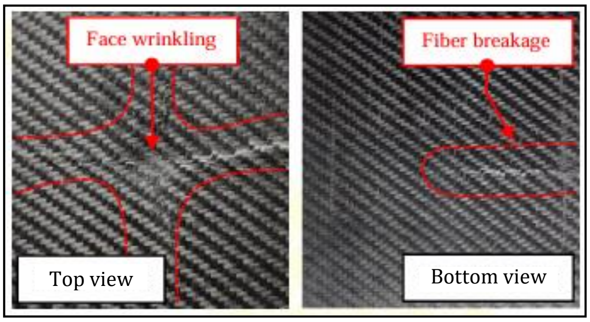


Figure 16. Impact failure at variation (90°)

The research results indicate the balsa wood grain orientation has a significant impact on both flexural strength and impact resistance. In the three point bending test, the 0° grain orientation produced a maximum average strength of 22.77 MPa. This value is substantially higher than the 90° orientation which only reached 9.39 MPa This disparity occurs because straight fibers are capable of optimally distributing the bending load along the grain length. Conversely the perpendicular grain orientation leads to uneven stress distribution, resulting in premature failure

A similar trend was observed in the drop weight impact testing, where the 0° grain orientation demonstrated superior impact energy absorption capacity compared to the other orientations (30°, 60°, and 90°). Thus, there is a consistent correlation indicating that straight grain orientation provides a much more optimal combination for withstanding both static and dynamic loads by minimizing crack propagation while simultaneously enhancing toughness.

CONCLUSIONS

The conclusions of this final project, from the procedures of data collection and processing for both bending and impact testing, are as follows

1. The variation in balsa wood grain orientation significantly influences the flexural strength of the sandwich composite. Specimens with grain aligned parallel to the load (0°) exhibited a maximum flexural strength of 22.77 MPa. Conversely the flexural strength tended to decrease at 30° (18.47 MPa), 60° (9.65 MPa) and 90° (9.39 MPa) orientations. This indicates that the 0° orientation allows the material to withstand bending loads optimally as the stresses are distributed directly along the fibers. In contrast, at the 90° orientation the load is primarily sustained by the matrix leading to a reduction in strength.
2. Visual damage analysis from both the three point bending and drop weight impact tests reveals several progressive failure stages. The failure sequence initiates with debonding followed by skin instability (face wrinkling) and core shear. Ultimately these mechanisms lead to tensile failure, delamination, and fiber breakage within the structure.

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