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Analysis of Flexural and Impact Strength of Woven Bamboo as a Substitute Material for Boat Hull Structures

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Abstract
This study aims to evaluate the mechanical properties of woven bamboo composites as a candidate material for replacing boat hulls. Bamboo was selected for its lightweight nature, relatively high strength, good elasticity, and environmentally friendly, renewable properties. The research method employed was laboratory experimentation conducted at the Mechanical Engineering Laboratory of Abulyatama University and the Laboratory of Lhokseumawe State Polytechnic through flexural and impact testing. The specimens were made from woven bamboo with a strip thickness of 10 mm, bonded with resin, and coated with fibreglass. The tests were conducted based on ASTM D790 standards for flexural testing and ASTM D256 standards for impact testing. This research was carried out from December 10, 2025, to January 14, 2026. The flexural test results showed that specimen B1 had the highest load-bearing capacity of 240.21 Kgf, with a maximum stress of 10.45 Kgf/mm² and a strain of 1.79%. The average maximum load of all specimens was 133.24 Kgf with an average strain of 5.13%. In the impact test, specimens A4 and A5 absorbed 12 Joules of energy, which is higher than the 10 Joules absorbed by specimens A1, A2, and A3. Overall, the results indicate that woven bamboo composites have good potential as an alternative material for boat hulls due to their lightweight characteristics, adequate strength, and support for environmental sustainability.

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1. Introduction

As an archipelagic country, Indonesia has enormous fisheries potential. However, the development of the fisheries industry still faces various challenges, particularly in terms of vessel technology and the selection of construction materials. The use of hardwoods such as ulin and teak is becoming increasingly limited due to their scarcity and high cost. In addition, metallic materials have disadvantages such as corrosion and relatively heavy weight. As a country with one of the longest coastlines in the world, Indonesia has significant potential to increase fish production, with an estimated capacity of up to 12 million tons per year based on the national fisheries policy (Wahyuni & Hidayat, 2022).
The selection of ship hull materials greatly determines vessel performance and service life. Therefore, alternative materials are needed that are lighter, stronger, more economical, and environmentally

friendly. Bamboo is a promising option due to its rapid growth, availability, and relatively good mechanical properties (Darma et al., 2017).

Bamboo offers several advantages when used as a shipbuilding material. Mechanically, bamboo has relatively high tensile and impact strength compared to conventional wood, along with good elasticity, allowing it to withstand high loads without cracking easily. Its flexible nature makes bamboo highly suitable for structures prone to impacts, such as ship hulls, which must endure water impact, collisions, and vibrations during operation. In addition, bamboo is known for its resistance to insects and decay, making it more durable than conventional wood. The processing of bamboo is also more environmentally friendly, as it is a renewable resource that can be replenished quickly without damaging ecosystems (Manik et al., 2020; Suwarno, 2018; Akasyah, Yusri, & Jihong, 2025).

However, despite its many advantages, the use of bamboo as a ship hull material still requires further research, particularly regarding its strength and resistance to impact and collision. One promising approach is the use of woven bamboo as a reinforcing material for ship hulls. Woven bamboo, made from strips arranged in specific patterns, is believed to enhance structural strength while improving flexibility and resistance to harsh marine environmental conditions (Wahyuni & Hidayat, 2022). This study aims to evaluate the strength of woven bamboo with a 3 cm strip thickness as a substitute reinforcing material for ship hulls, to determine the extent to which bamboo can replace conventional materials in fishing vessel construction.

The development of bamboo woven with resin and fibreglass is expected to improve its structural strength. This study is conducted to determine the capability of woven bamboo composites to replace conventional materials in boat hulls, particularly in resisting flexural loads and impacts (Darma et al., 2017; Sapee, Yusop, Kadarohman, & Khoerunnisa, 2025).

Through this research, it is expected that valid data will be obtained on the potential of bamboo as a feasible alternative to conventional materials in fishing vessel construction. In addition, this study aims to introduce bamboo as a more environmentally friendly, cost-effective, and efficient raw material in supporting the sustainability of Indonesia's fisheries industry (Liu et al., 2025; Leman & Jalaludin, 2025; Mekkah et al., 2025). In this study, specimens are produced by weaving bamboo, bonding it with Yucalak resin, and coating it with fibreglass. These specimens serve as test materials to evaluate flexural and impact strength, thereby determining whether bamboo can be used as a strong, lightweight, and environmentally friendly substitute material for boat hulls.

2. Methodology

Time

This study was conducted from December 10, 2025, to January 14, 2026, for approximately 1 month. During this period, several important stages of the research were carried out systematically and in a well-planned manner. The process began with initial preparation, including developing the research plan, selecting appropriate methods, and preparing the required tools and materials. This was followed by the data collection phase, conducted carefully and thoroughly to ensure the obtained information accurately reflected actual conditions.

Location

The fabrication and preparation of specimens were carried out at the Mechanical Engineering Laboratory, Universitas Abulyatama, located in Kota Baro District, Aceh Besar Regency, Aceh Province. Meanwhile, the specimens were tested at the Laboratory of Lhokseumawe State Polytechnic.

Tools and Materials

This study utilised several tools and materials, including a flexural testing machine, a Charpy impact testing machine, a vernier calliper, measuring tools, cutters, Yucalak resin, moulds, 10 mm woven bamboo, and fibreglass mat (types 300 and 450).

Testing Method

The flexural test was conducted using a GALDABINI bending testing machine with a maximum capacity of 100 kN. In this test, the specimen was placed on two supports, and a load was applied at its midpoint, causing it to bend. The purpose of the flexural test is to determine the mechanical properties of the material, such as flexural strength, modulus of elasticity, and material behaviour under bending conditions (Supomo & Djatmiko, 2021; Susilawati, 2026; Hadi, Abnisa, & Pranoto, 2026). The impact test was performed using a MATEST impact testing machine with a maximum capacity of 300 Joules (32 kg). In this test, woven bamboo specimens were subjected to impact loading until they cracked or fractured. The purpose of the impact test is to evaluate the material's ability to absorb impact energy without failure.

Fig. 1. Flexural testing machine and impact testing machine

Figure 1 illustrates the equipment used in this study, namely the flexural testing machine and the Charpy impact testing machine. In the flexural test, the applied load causes deformation in the material as the specimen bends under a centrally applied force. The specimen is supported at two supports, and the load is applied at the midpoint, resulting in bending stress. The results of this test are used to determine important mechanical properties such as flexural strength and modulus of elasticity, which indicate the material's ability to withstand bending loads without failure (Wahyuni & Hidayat, 2022; Sartika, Sardjono, & Jalaludin, 2026; Lin, Efremov, & Maawa, 2026).

Meanwhile, the impact test shown in Figure 1 evaluates the material's ability to absorb energy under sudden loading conditions. In this test, the woven bamboo specimen is subjected to an удар (impact) load until fracture occurs. The energy absorbed during fracture reflects a material's toughness. This test is particularly important for assessing the feasibility of woven bamboo as a substitute material for boat hulls, as hull structures are frequently exposed to impacts from waves, floating objects, and docking conditions. Therefore, high impact resistance is essential to ensure durability and safety in marine environments. Overall, the combination of flexural and impact testing, as illustrated in Figure 1, provides a comprehensive understanding of the mechanical behaviour of woven bamboo composites, particularly their ability to resist bending loads and absorb impact energy. These properties are critical in evaluating the suitability of bamboo composites as an alternative material for boat hull applications.

3. Result & Discussion

Flexural Test

Flexural Strength Test Specimens

The bending (flexural) test was conducted to evaluate the mechanical properties of woven bamboo composite materials, particularly the maximum bending load, maximum stress, and strain. The test was conducted at the Material Testing and Characterisation Laboratory, Department of Mechanical Engineering, Lhokseumawe State Polytechnic, using a GALDABINI bending testing machine with a maximum capacity of 100 kN. Based on the flexural test results of five specimens, variations were observed in bending load, maximum stress, and strain values. These variations were influenced by factors such as specimen dimensions, the quality of the woven bamboo, and the uniformity of the resin used in the composite fabrication. The test results are presented in **Table 1**.

Table 1. Flexural Test Specimens Before, During, and After Testing

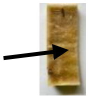
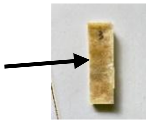
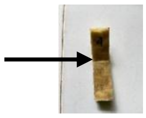
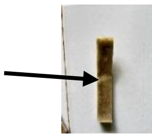
Sample	Before Testing	Testing Process	Test Results
B1			
B2			
B3			
B4			
B5			

Table 1 illustrates the flexural testing results of five woven bamboo composite specimens (B1 to B5). Each specimen was initially intact before testing, with no visible damage. During testing, the specimens were placed on a flexural testing machine, where a load was applied to evaluate their bending strength. The test result images show the changes in each specimen after flexural loading. Some specimens exhibited damage or deformation under the applied load, providing important information on the material's resistance to bending.

Furthermore, Table 1 indicates that the deformation patterns observed after testing provide insight into the failure behaviour of the woven bamboo composite. Several specimens exhibit localised bending and cracking at the mid-span region, consistent with the point of maximum stress concentration during the flexural test. This suggests that the bonding quality between the bamboo fibres, resin, and fibreglass layers is crucial in determining the composite's structural integrity. Specimens with more uniform deformation tend to exhibit better load distribution, whereas those with visible cracks or fractures indicate weaker interfacial bonding or compositional inconsistencies. Therefore, improving the fabrication process, particularly resin distribution and fibre alignment, is essential to enhance the overall flexural performance of the woven bamboo composite.

Data hasil penelitian kekuatan lentur

Table 2 presents the results of the flexural testing of woven bamboo composite materials based on laboratory data. The data include load (F), stress (σ), and strain (ε) for each specimen. The flexural test results shown in the table illustrate the values obtained during testing, including the maximum bending load, maximum flexural stress, and the strain experienced by each tested specimen. These parameters provide important information regarding the mechanical performance of the woven bamboo composite under bending loads.

Table 2. Flexural Test Results of Woven Bamboo Composite Specimens

Test Material	Specimen	Cross Section	Support Span	Maximum Load (Fu)	Maximum Stress (σu)	Strain (ε)
		(mm²)	(mm)	(Kgf)	(Kgf/mm²)	(%)
Composite (Woven Bamboo & Resin)	B1	50 x 10	145	240.21	10.45	1.79
	B2	50 x 11	146	73.24	3.19	7.91
	B3	50 x 12	147	112.86	4.91	5.78
	B4	50 x 13	148	73.24	3.19	7.95
	B5	50 x 14	149	166.63	7.25	2.2
	Average			**133.24**	**5.80**	**5.13**

Furthermore, **Table 2** indicates a significant variation in flexural performance among the specimens. Specimen B1 exhibits the highest maximum load (240.21 Kgf) and maximum stress (10.45 Kgf/mm²), indicating superior strength compared to the other specimens. In contrast, specimens B2 and B4 show lower load and stress values but higher strain, suggesting greater flexibility. The average values for all specimens are 133.24 kN for load, 5.80 kN/mm² for stress, and 5.13% for strain, providing a general overview of the material's mechanical behaviour. These results demonstrate that while the woven bamboo composite has adequate strength, its performance is influenced by variations in specimen dimensions, material uniformity, and bonding quality between bamboo, resin, and fibreglass.

Table 2 presents the results of the bending (flexural) test for five woven bamboo–resin composite specimens with varying dimensions and support spans. All tested specimens have the same cross-sectional length (50 mm), but different widths and thicknesses, which influence the maximum load each specimen can withstand before failure. The maximum load ranges from 73.24 Kgf for specimen B2 to 240.21 Kgf for specimen B1. The maximum stress (σu) also varies among the specimens, with the highest value observed in B1 (10.45 Kgf/mm²) and the lowest in B2 and B4 (3.19 Kgf/mm²). The strain (ε) values also differ, where B2 and B4 exhibit the highest strain values, 7.91% and 7.95%, respectively, indicating that these specimens are more elastic compared to the others. The average maximum load, stress, and strain for all specimens are 133.24 kN, 5.80 kN/mm², and 5.13%, respectively, providing a general overview of the composite material's strength and flexibility.

Based on the test data, the variation in the cross-sectional dimensions of specimens B1-B5, with thicknesses ranging from 10 mm to 14 mm, indicates a lack of uniformity in the manufacturing process of the woven bamboo–resin composite. These differences in thickness require adjustments to the support span, which increase gradually from 145 mm to 149 mm to maintain a consistent testing ratio in accordance with flexural testing standards. Despite variation in specimen dimensions, stress and strain calculations were consistently performed for each specimen, yielding an average flexural stress of 5.80 kN/mm² and an average maximum load of 133.24 kN.

Fig. 2 illustrates the variation of maximum load, stress, and strain for woven bamboo composite specimens (B1–B5) obtained from flexural testing. The graph shows that specimen B1 exhibits the highest maximum load (240.21 Kgf), followed by B5 (166.63 Kgf), while B2 and B4 exhibit the lowest (73.24 Kgf). A similar trend is observed in the stress distribution, with B1 recording the highest stress (10.45 kN/mm²), indicating superior load-bearing capacity compared to the other specimens. This variation suggests that specimen geometry and material consistency significantly influence the composite's flexural performance.

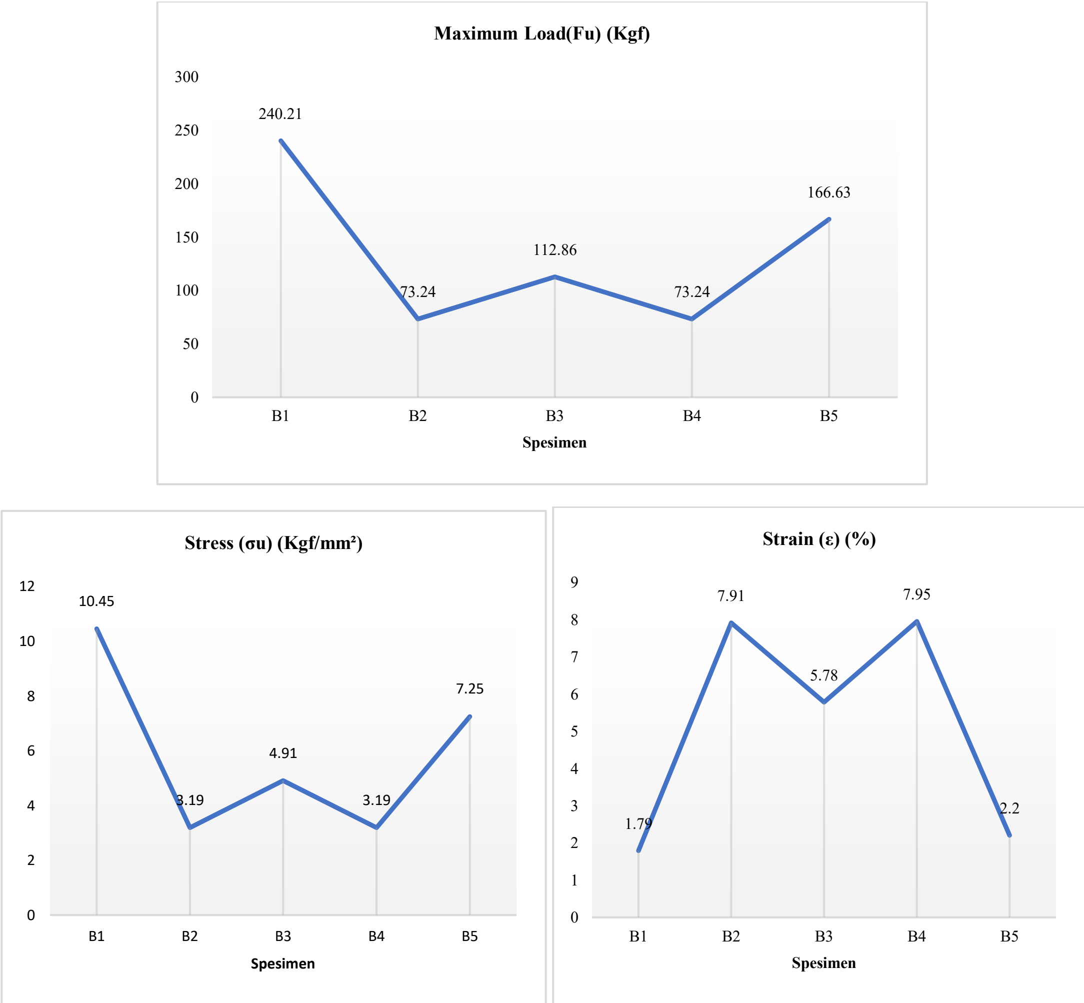


Fig. 2. Variation of Maximum Load, Stress, and Strain in Woven Bamboo Composite Specimens

In contrast, the strain graph shows a different trend: specimens B2 and B4 exhibit the highest strain values (7.91% and 7.95%, respectively), indicating greater flexibility and ductility. Meanwhile, specimen B1 shows the lowest strain (1.79%), suggesting that although it has high strength, it is relatively less deformable. This inverse relationship between stress and strain indicates that specimens with higher strength tend to exhibit lower deformation, while those with lower strength tend to be more elastic. Such behaviour is typical of composite materials, where stiffness and flexibility are often influenced by fibre distribution and the quality of matrix bonding.
Overall, the results presented in **Fig. 2** highlight the trade-off between strength and flexibility in woven bamboo composites. Specimens with higher load and stress values, such as B1, are more suitable for structural applications requiring high strength, while specimens with higher strain values, such as B2 and B4, may perform better in applications requiring greater energy absorption and flexibility. These findings indicate that optimising the fabrication process, particularly in terms of uniform thickness, fibre alignment, and resin distribution, is essential to achieve balanced mechanical performance in boat hull applications.

Several studies on the flexural behaviour of bamboo–resin composites have shown that variations in dimensions and material types significantly influence their mechanical properties, including

maximum load, stress, and strain. As reported by Zhang et al. (2019); Gassan and Bledzki (2001); Muthukumar and Rajesh (2018), variations in the width and thickness of bamboo composites can enhance flexural strength and the material's ability to withstand maximum loads, while also affecting its elasticity. These studies indicate that thicker, wider bamboo composites, combined with longer support spans, tend to exhibit higher maximum load capacity and higher stress values, although their elasticity may decrease.
Similar results are observed in the flexural tests of specimens B1 to B5: specimens with larger dimensions (such as B1) demonstrate higher maximum load capacity, while specimens with smaller dimensions (B2 and B4) exhibit higher strain values, indicating greater elasticity. These findings confirm a strong relationship between specimen dimensions and the mechanical properties of bamboo–resin composites in structural applications (Setiawan & Wiryawan, 2018; Darma et al., 2017; Bo, Farid, & Said, 2026).

Impact Test
Test Specimens
The Charpy impact test was conducted to evaluate the mechanical properties of woven bamboo composite materials, particularly the absorbed energy and impact value. The testing was carried out at the Material Testing and Characterisation Laboratory, Department of Mechanical Engineering, Lhokseumawe State Polytechnic, using a MATEST impact testing machine with a maximum capacity of 300 Joules (32 kg). Based on the impact test results of five specimens, variations were observed in the absorbed energy (E) and impact value (HI). These variations are influenced by factors such as specimen dimensions, the quality of the woven bamboo, and the uniformity of the resin used in the composite fabrication. The test results are presented in Table 3, which shows the condition of the specimens before testing, during testing, and after impact loading.

Table 3. Condition of Specimens Before, During, and After Impact Testing

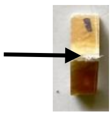
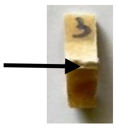
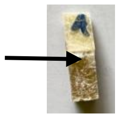
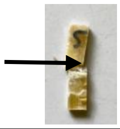
Specimen	Before Testing	Testing Process	Test Results
A1			
A2			
A3			
A4			
A5			

Table 3 indicates that all specimens were initially in intact condition before testing, with no visible defects. During testing, each specimen was subjected to a sudden impact load using the Charpy testing machine. After testing, visible (fracture) and deformation were observed in all specimens, indicating that energy absorption occurred until failure. The differences in fracture patterns among specimens suggest variations in material toughness and internal bonding quality. Furthermore, the post-test observations in **Table 3** reveal that some specimens exhibit more severe fractures and fragmentation than others, indicating a higher energy-absorption capacity before failure. Specimens with cleaner, more brittle fractures tend to absorb less energy, whereas those showing greater deformation or fibre pull-out behaviour indicate better toughness. This suggests that the interfacial bonding between the bamboo fibres, the resin, and the fibreglass layers strongly influences the mechanical performance of the woven bamboo composite. Therefore, improving material uniformity and bonding quality is essential to enhancing the composite's impact resistance, particularly in boat hull structures subjected to dynamic loading conditions.

Research Data Results

Table 4 presents the results of the Charpy impact test conducted on woven bamboo–resin composite specimens. Each specimen was tested by measuring the length below the notch (a), specimen thickness (b), and cross-sectional area (A). The energy absorbed by the specimen during the impact test is recorded as E (in Joules), representing the amount of energy the material can absorb before fracture occurs. The impact value (HI) is calculated by dividing the absorbed energy (E) by the cross-sectional area (A), expressed in Joules per mm², which indicates the material's resistance to impact relative to its size. The results of the impact testing of the woven bamboo composite material are presented in **Table 4**.

Table 4. Impact Test Results of Woven Bamboo–Resin Composite Specimens

Test Material	Specimen	Length (a)	Thickness (b)	Cross-sectional area (A)	Absorbed Energy (E)	Impact Value (HI)
		(mm)	(mm)	(mm²)	(Joule)	(Joule/mm²)
Woven Bamboo–Resin Composite	A1	10	9	90.0	10.0	0.111
	A2	10	9	90.0	10.0	0.111
	A3	10	9	90.0	10.0	0.111
	A4	10	9	90.0	12.0	0.133
	A5	10	9	90.0	12.0	0.133
	Average					**0.120**

Furthermore, **Table 4** shows that all specimens have identical dimensions (length of 10 mm, thickness of 9 mm, and cross-sectional area of 90 mm²), indicating that material properties rather than geometric differences primarily influence the variations in impact performance. Specimens A1, A2, and A3 exhibit the same absorbed energy value of 10 Joules and an impact value of 0.111 Joule/mm², while specimens A4 and A5 show a higher absorbed energy of 12 Joules and an impact value of 0.133 Joule/mm². The average impact value for all specimens is 0.120 Joule/mm². These results suggest that certain specimens exhibit greater impact resistance, likely due to improved bonding quality and greater structural integrity within the composite. The relatively consistent values also indicate that the woven bamboo–resin composite exhibits stable, reliable impact performance, making it a promising candidate for applications requiring resistance to sudden loading, such as boat hull structures.

Table 4 presents the results of the Charpy impact test for five specimens (A1, A2, A3, A4, and A5). All specimens have identical dimensions: a length of 10 mm, a thickness of 9 mm, and a consistent cross-sectional area of 90 mm². The absorbed energy (E) for specimens A1, A2, and A3 is 10.0 Joules, while specimens A4 and A5 show higher absorbed energy values of 12.0 Joules. The impact value (HI) is calculated as the absorbed energy divided by the cross-sectional area. Specimens A1, A2, and A3 exhibit an HI value of 0.111 Joule/mm², whereas A4 and A5 show higher values of 0.133 Joule/mm². The average impact value for all specimens is 0.120 Joule/mm², indicating the material's ability to absorb impact energy per unit area. Previous studies by Liu et al. (2018) on bamboo fibre-reinforced polymer composites demonstrate that bamboo-based composites exhibit good impact resistance, consistent with this study's findings, in which increased absorbed energy corresponds to improved impact performance. Furthermore, Sreekala and Thomas (2003) reported that higher impact energy absorption is typically associated with more elastic composite materials, which aligns with the higher impact values observed in specimens A4 and A5.

The relatively small variation in impact values (HI) among the specimens can be attributed to their uniform dimensions. All specimens (A1-A5) have consistent length, thickness, and cross-sectional area, resulting in similar calculated impact values. The primary difference lies in the absorbed energy (E), which is higher in specimens A4 and A5 (12.0 Joules) compared to A1, A2, and A3 (10.0 Joules). However, despite the increase in absorbed energy for specimens A4 and A5, the calculated impact values (HI), expressed as energy per unit area (Joule/mm²), do not show a significant difference between the groups. Specimens A1, A2, and A3 yield an HI value of 0.111, while A4 and A5 reach 0.133, representing only a slight increase. This indicates that although energy absorption improves, the difference is not substantial enough to produce a significant variation in impact value per unit area, as other factors, such as specimen geometry and material consistency, remain constant.

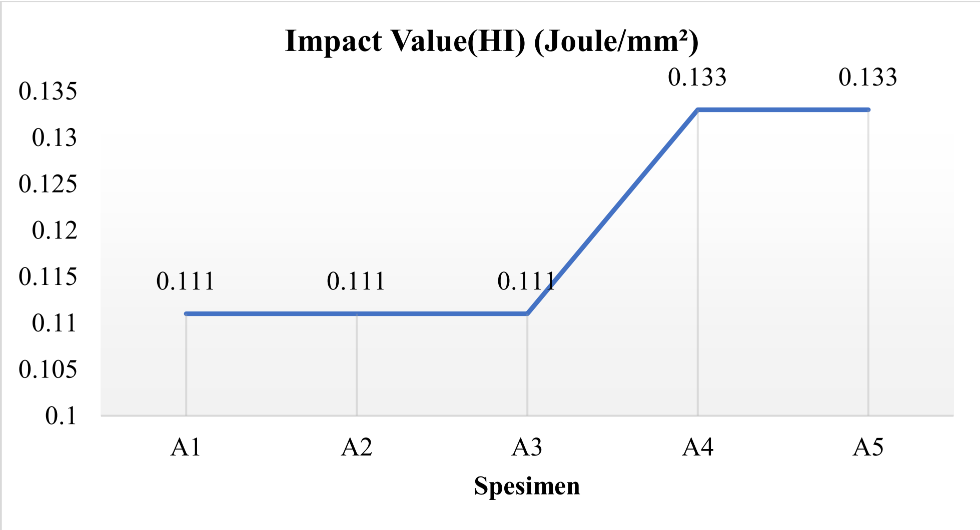


Fig. 3. Impact Strength of Woven Bamboo–Resin Composite Specimens

Fig. 3 illustrates the variation in impact strength (HI) of woven bamboo–resin composite specimens (A1–A5). The results show that specimens A1, A2, and A3 have identical impact strength values of 0.111 Joule/mm², indicating consistent energy-absorption performance among these samples. In contrast, specimens A4 and A5 exhibit higher impact strength values of 0.133 Joule/mm², suggesting improved resistance to impact loading. This increase indicates that some specimens can absorb more energy before failure, reflecting improved toughness. The relatively small difference between the two groups suggests that, while there is an improvement in impact resistance, the overall performance remains relatively uniform due to the in-specimen dimensions and testing conditions. These findings confirm that the woven bamboo–resin composite exhibits stable, reliable impact behaviour, with slight variations likely due to differences in material bonding quality and internal structure.

4. Conclusion

Based on the research results, the woven bamboo composite material combined with Yucalak resin and fibreglass demonstrates good mechanical performance, particularly in resisting flexural and impact loads. In the flexural test, specimen B1 exhibited the highest maximum load of 240.21 Kgf, with a stress value of 10.45 Kgf/mm² and a strain of 1.79%, while the other specimens showed variations in load and strain, with an average maximum load of 133.24 Kgf and an average strain of 5.13%. In the impact test, specimens A4 and A5 absorbed higher energy (12.0 Joules) compared to A1, A2, and A3 (10.0 Joules), although the differences in impact strength among the specimens were not highly significant. Overall, the woven bamboo composite shows strong potential as an alternative to conventional materials for boat hull applications, thanks to its lightweight characteristics, adequate strength, and environmental friendliness.

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