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The Effect of Banana Frond Waste Fibers Compared to Glass Fibers on The Mechanical Properties of Composites

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banana frond waste fibers; glass fibers; mechanical properties; composites; sustainable materials; natural fibers

ABSTRACT

This study investigates the mechanical properties of composites reinforced with banana frond waste fibers compared to those reinforced with traditional glass fibers. The increasing environmental concerns and the need for sustainable materials have driven the exploration of natural fibers as viable alternatives to synthetic fibers in composite materials. Banana frond waste, a byproduct of banana cultivation, offers a renewable and biodegradable option for composite reinforcement. Composites were fabricated using both banana frond waste fibers and glass fibers, and their mechanical properties, including tensile strength, bending strength, and impact resistance, were evaluated and compared. The results indicated that while glass fiber composites exhibited higher overall mechanical performance, banana frond waste fiber composites showed competitive properties, particularly in terms of impact resistance and specific strength. The natural fibers demonstrated adequate bonding with the polymer matrix, contributing to the composite's overall integrity. Moreover, the use of banana frond waste fibers significantly reduced the composite's environmental footprint, making them a promising alternative for various applications where moderate mechanical performance is sufficient. The study highlights the potential of banana frond waste fibers as a sustainable reinforcement material, encouraging further research and development in this area to optimize their mechanical properties and broaden their application scope.

1. INTRODUCTION

When two are more physically and chemically different materials are combined with a distinct interface between the materials to form a single substance it can be called as composite [1]. Composites are versatile groups of compounds that can be seen in unexpected applications. Dependence of composites are extensively increased due to the desire for material durability, high modulus, chemical inertness, flame retardance and thermal isolation. The composite materials are broadly classified into three major categories: polymer matrix, metal matrix, and ceramic matrix [1][2]. Since the dawn of human civilization, mankind has been utilizing the available materials for their convenience. In the starting eras, due to lack of technological advances, natural materials such as wood, clay, and stone were prominently used [3]. The principle in fiber composites is to utilize fibers as reinforcement in matrix of resin. Fibers usually provide the greatest share of strength while resin provides binding to the fibers. Fibers by themselves cannot be used to sustain actual loads. Therefore, resin is used to bind and protect the fibers. Depending on the type of fibers, type of resin, the proportion of fiber-resin and the type of manufacturing process, the properties of fiber composites can be tailored to achieve the desired end product. In similar manner, natural fibers can also be used to produce fiber composites [4]. Talking about natural fiber, Natural fibers have received a lot of attention as possible alternative replacement for synthetic fibers, as reinforcement of various resins for advanced applications due to their properties, such as: low density, high specific strength and they are renewable, sustainable, and eco-friendly [5][6][7]. The banana fiber extraction process was conducted with the leaf sheaths which were cut down from the pseudo-stem of the plant [8]. Bananas are one of the germplasm that is widespread in the territory of Indonesia [9]. Banana tree waste is easy to get and the price is not expensive [10]. Banana fiber at present is a waste product of banana cultivation. Moreover, without any additional cost input, banana fiber can be obtained in bulk quantity [6]. There have been several previous studies that have used banana fiber as the main raw material for composites, including such as [11]. This study evaluated the mechanical properties of hybrid composites reinforced with banana fiber and eggshell powder in an epoxy matrix. The results show a significant increase in mechanical strength, making this material potential for sustainable engineering applications. Next Before that, synthetic fibers were used long before the existence of natural fibers. One of them is glass fiber, talking about glass fiber, Glass fibers have been known for centuries but there were few utilitarian uses for them until the middle of the nineteenth century [12]. Fiberglass or in Indonesian known as fiber glass and glass fiber is liquid glass that is pulled into thin fibers with a diameter of about 0.005 to 0.01 mm [13]. According [14]. The advantage of hemp fiber composite compared to fiber glass is that hemp fiber composite is more environmentally friendly because it is able to be biodegradable naturally and the price is cheaper than fiber glass. Meanwhile, fiber glass is difficult to biodegrade naturally. In addition, fiber glass also produces CO gas and dust that are harmful to health if fiber glass is recycled, so there is a need for alternative materials to replace the fiber glass. To determine the mechanical properties of the composite, it is necessary to perform mechanical tests respectively for banana frond fiber reinforced composites and glass fibers as a comparison by using ASTM D 638M-93 standards for tensile tests, ASTM D790 for bending tests, ASTM D265 for impact tests.

2. METHODS

2.1 Testing Equipment

We can see in Fig. 1, it is a tool used for strength testing of composite specimens that has been made, including (a) tensile test device, (b) bending test device, and (c) impact test device.

(a) (b) (c)

Figure 1. (a) Tensile test device, (b) bending test device, and (c) impact test device.

2.2 Tools

2.2.1 Extractor Tool

This tool is used to extract natural plant fibers such as banana stem fibers, this tool has been developed by [15] and can extract other natural plant fibers as seen in Fig 2.

Figure 2. Extractor tool.

In previous research [8] also extract banana plant fibers using different tools with grooves as follows.

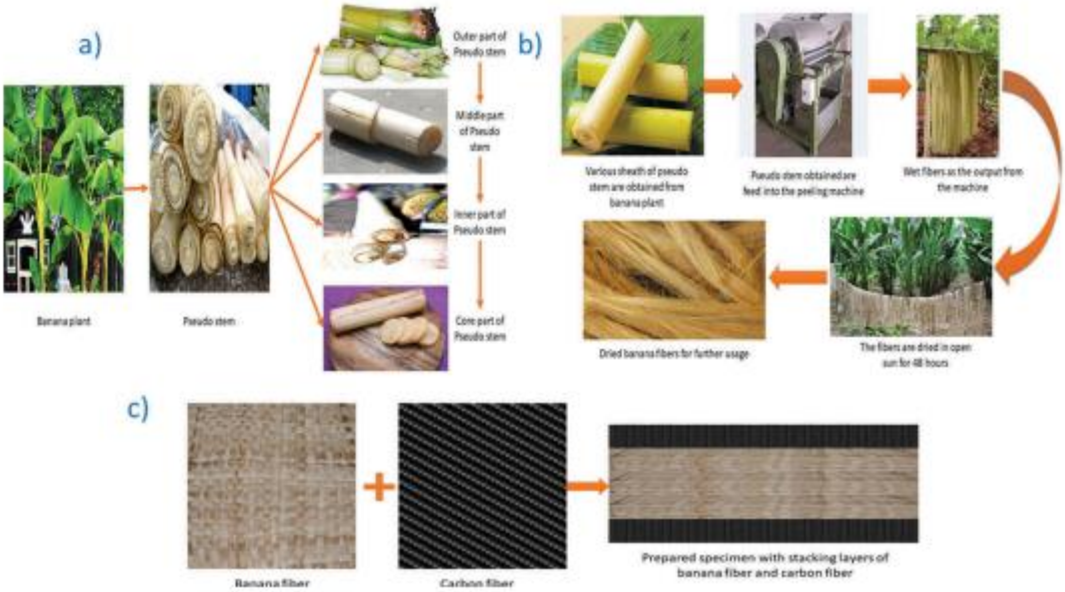
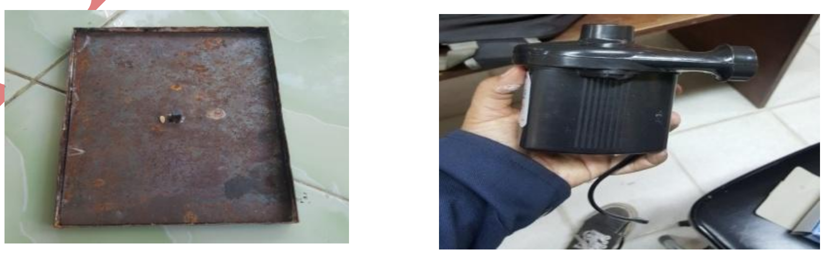


Figure 3. Composite preparation. (a) Pseudo-stem extraction from banana plant, (b) preparation of banana fibers, and (c) specimen preparation using banana and carbon fibers [8].

2.2.2 Composite Press and Vacuum Pumps

These tools are used to print composites from pressed and vacuumed natural plant fiber materials as seen in Fig. 4.



(a) (b)

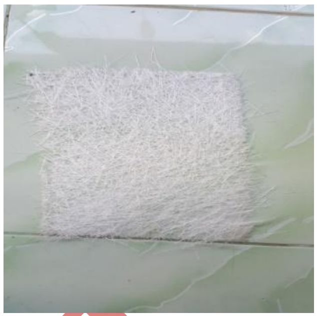
Figure 4. (a) Composite presses and (b) vacuum pumps.

2.3 Material

The materials used in this study are banana stem fiber, resin, glass fiber, catalyst, talc powder as seen in Fig. 5.

(a)

(b)



(c)

(d)

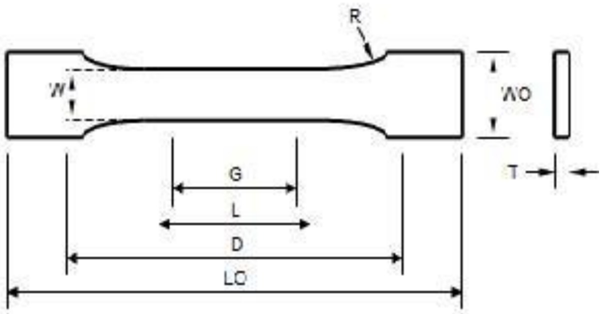
(e)

Figure 5. (a) Banana stem fiber, (b) resin, (c) glass fiber, (d) catalyst and (e) talc powder.

2.4 Testing Specimen

2.4.1 Tensile Testing

Tensile tests are used to determine how materials behave under tension load. In a simple tensile test, a sample is typically pulled to its breaking point to determine the ultimate tensile strength of the material [16]. For tensile testing for the specimens here use ASTM D 638M-93 standard, as seen in Fig. 6 and Table 1.



(a)

(b)

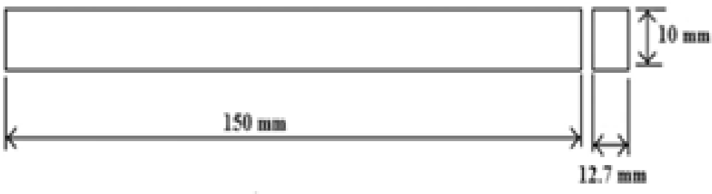
Figure 6. (a) Design specimen standard ASTM D 638M-93 and (b) result of specimen fabrication.

Table. 1 Tensile test specimen dimensions.

Dimension	Long	Tolerance
W, narrow area width	10 mm	± 0,5 mm
L, narrow area length	60 mm	± 0,5 mm
WO, overall width	20 mm	± 0,5 mm
LO, overall length	250 mm	No max
G, measure length	60 mm	± 0,25 mm
R, radius curvature	60 mm	±1 mm
T, Thickness	8 mm	± 0,2 mm
D, Distance between grips	115 mm	± 0.5 mm

2.4.2 Bending Testing

Bending test is a form of testing to visually determine the quality of a material [17]. For bending testing for the specimens here use ASTM D790 standard as seen in figure 7.



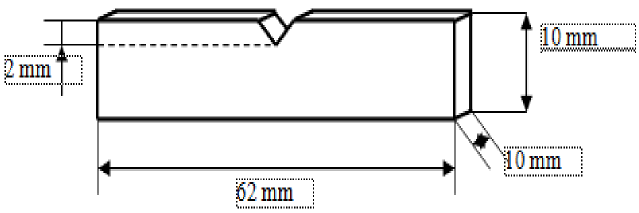
(a)

(b)

Figure 7. (a) Design specimen standard ASTM D790 and (b) result of specimen fabrication.

2.4.3 Impact Testing

Impact testing to determine the strength of impact [17]. For Impact testing for the specimens here use ASTM D265 standard as seen in figure 8.



(a)

(b)

Figure 8. (a) Design specimen standard ASTM D265 and (b) result of specimen fabrication.

3. RESULT AND DISCUSSION

3.1 Test Result Data

3.1.1 Tensile Testing Result Data

We can see data collection was carried out by tensile testing (Tables 2, 3, 4, 5 and 6). The following information: fracture cross-sectional area A (mm²), tensile force Fm (N), yield stress (σ_y) (N/mm²), tensile strength (σ) (N/mm²), tensile strain (ε) (%), width L (mm), maximum load Fm (N), bending stress (σ_b) (N/mm²), thickness (t) (mm), notch (N) (mm), energy (E) (Joule), impact price HI (joule/mm²).

Table 2. Pure resin specimen tensile test data.

Specimens	A (mm²)	F_m (N)	σ_y (N/mm²)	σ (N/mm²)	ε (%)
Pure Resin Composite	80	2440	15.8	30.5	7

Table 3. Straight banana stem fiber specimen tensile test data.

Specimens	**A (mm^2)**	**F_m (N)**	**σ_y (N/mm^2)**	**σ (N/mm^2)**	**ε (%)**
1 Layer Straight Fiber Press	80	2245	12.90	28.06	5
1 Layer Vacuum Straight Fiber	80	3329	12.57	41.61	11
2 Layers of Straight Fiber Press	80	606	3.37	7.57	3
2 Layers of Vacuum Straight Fiber	80	2000	13.73	25.00	5

Table 4. Transverse banana stem fiber specimen tensile test data.

Specimens	**A (mm^2)**	**F_m (N)**	**σ_y(N/mm^2)**	**σ (N/mm^2)**	**ε (%)**
1 Layer of Pressed Transverse Fiber	80	1817	10.85	22.72	7
1 layer of vacuum transverse fiber	80	1399	8.74	17.49	6
2 Layers of Pressed Transverse Fiber	80	1132	8.51	14.15	4
2 Layers of Vacuum Transverse Fiber	80	1817	10.18	22.72	6

Table 5. Random banana stem fiber specimen tensile test data.

Specimens	**A (mm^2)**	**F_m (N)**	**σ_y (N/mm^2)**	**σ (N/mm^2)**	**ε (%)**
1 Layer Random Fiber Press	80	1983	7.77	24.79	6
1 Layer Vacuum Random Fiber	80	2651	11.92	33.13	3
2 Layers of Random Fiber Press	80	2073	12.81	29.51	9
2 Layers of Vacuum Random Fiber	80	1003	6.32	12.54	4

Table 6. Fiberglass specimen tensile test data.

Specimens	**A (mm^2)**	**F_m (N)**	**σ_y (N/mm^2)**	**σ (N/mm^2)**	**ε (%)**
1 Layer Fiberglass Press	80	1956	5.48	24.45	6
1 Layer Fiberglass Vacuum	80	982	11.50	37.28	6
2 Layers of Fiberglass Press	80	2572	15.12	32.15	6
2 Layers Vacuum Fiberglass	80	3106	18.81	38.82	8

After obtaining the results of the tensile test as in the table above of each variation, then the overall tensile force data is taken from each table so that a graph as shown in Fig. 9. It can be seen from the graph that composites with vacuum treatment have better tensile strength compared to others such as 1-layer straight fiber and also 2-layer fiberglass fiber in vacuum.

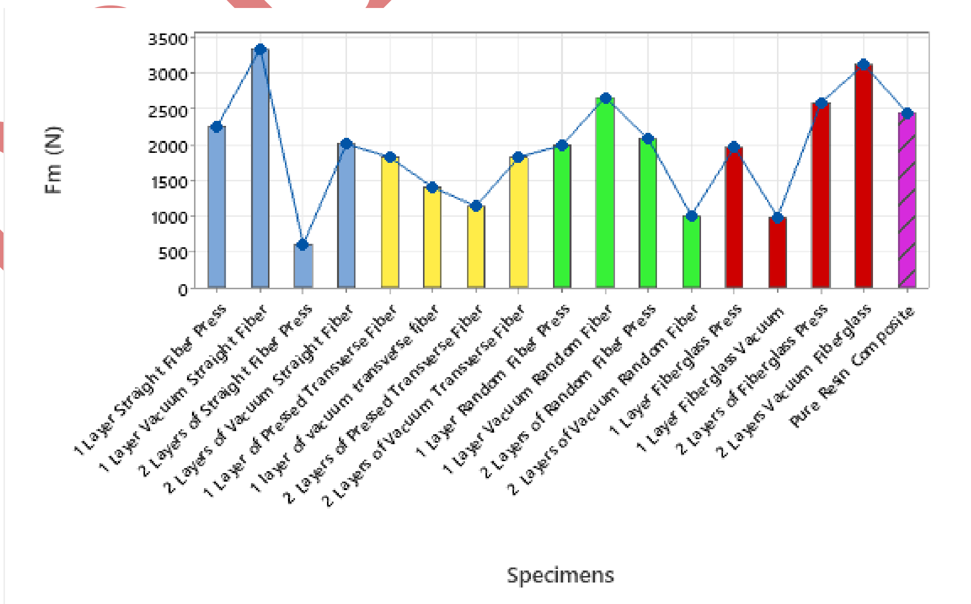


Figure 9. Chart of tensile force.

3.1.2 Bending Testing Result Data

We can see data collection was carried out by bending testing (Tables 7, 8, 9, 10 and 11). The following information: fracture cross-sectional area A (mm^2), tensile force Fm (N), yield stress (σ_y) (N/mm^2), tensile strength (σ) (N/mm^2), tensile strain (ε) (%), width L (mm), maximum load Fm (N), bending stress (σ_b) (N/mm^2), thickness (t) (mm), notch (N) (mm), energy (E) (Joule), impact price HI (joule/mm^2).

Table 7. Pure resin specimen bending test data.

Specimens	A (mm^2)	L (mm)	F_m (N)	σ_b (N/mm^2)
Pure Resin Composite	127	50	105	6.20

Table 8. Straight banana stem fiber specimen banding test data.

Specimens	A (mm^2)	L (mm)	F_m (N)	σ_b (N/mm^2)
1 Layer Straight Fiber Press	127	50	129.69	7.66
1 Layer Vacuum Straight Fiber	127	50	213.88	12.63
2 Layers of Straight Fiber Press	127	50	174.54	10.31
2 Layers of Vacuum Straight Fiber	127	50	180.26	10.65

Table 9. Transverse banana stem fiber specimen bending test data.

Specimens	A (mm^2)	L (mm)	F_m (N)	σ_b (N/mm^2)
1 Layer of Pressed Transverse Fiber	127	50	108.59	6.41
1 layer of vacuum transverse fiber	127	50	205.18	12.12
2 Layers of Pressed Transverse Fiber	127	50	151.74	8.96
2 Layers of Vacuum Transverse Fiber	127	50	157.91	9.33

Table 10. Random banana stem fiber specimen bending test data.

Specimens	A (mm^2)	L (mm)	F_m (N)	σ_b (N/mm^2)
1 Layer Random Fiber Press	127	50	225.50	13.32
1 Layer Vacuum Random Fiber	127	50	374.98	22.14
2 Layers of Random Fiber Press	127	50	267.41	15.79
2 Layers of Vacuum Random Fiber	127	50	271.15	16.01

Table 11. Fiberglass specimen bending test data.

Specimens	A (mm^2)	L (mm)	F_m (N)	σ_b (N/mm^2)
1 Layer Fiberglass Press	127	50	164.04	9.69
1 Vacuum Fiberglass Layer	127	50	250.91	14.82
2 Layers of Fiberglass Press	127	50	210.26	12.42
2 Layers Vacuum Fiberglass	127	50	240.29	14.19

Based on the bending force graph (Fig. 10), it can be concluded that the type of fiber, manufacturing method, and number of layers greatly affect the bending strength of composite materials. Specimens with random fibers show the highest performance, especially in the two-layer configuration with the vacuum method, which achieves a maximum force value of about 370 N. This shows that the random fibers are able to distribute the bending load more evenly. In general, the vacuum method tends to provide better results than conventional presses, especially when combined with two layers of fiber. In addition, increasing the number of layers from one to two consistently increases the bending strength of almost any type of fiber. In contrast, specimens without fibers (pure resins) have the lowest bending strength, confirming the importance of using fibers in reinforcing composite materials.

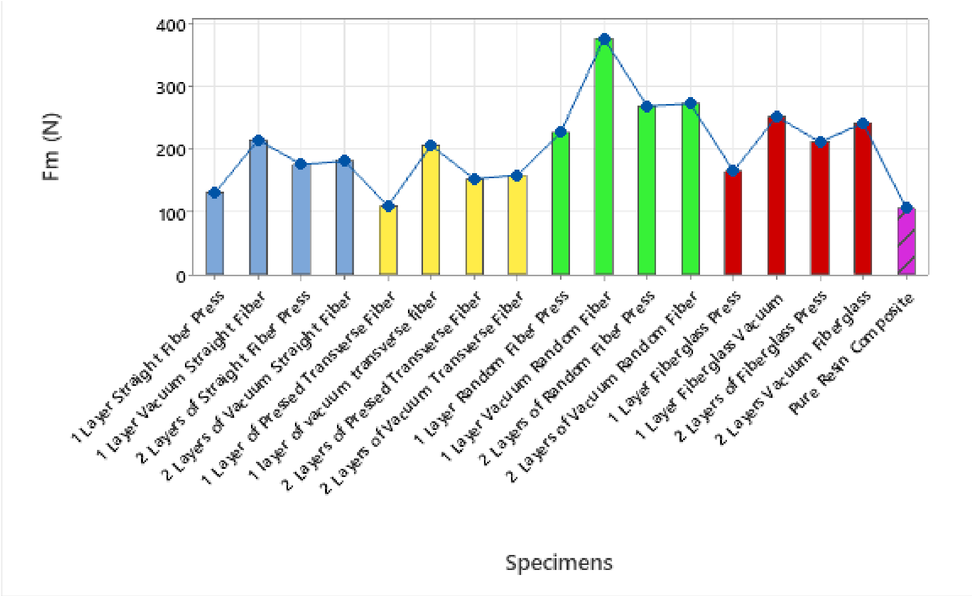


Figure 10. Chart of bending force.

3.1.3 Impact Testing Result Data

We can see data collection was carried out by impact testing (Tables 12, 13, 14, 15 and 16). The following information: fracture cross-sectional area A (mm²), tensile force Fm (N), yield stress (σ_y) (N/mm²), tensile strength (σ) (N/mm²), tensile strain (ε) (%), width L (mm), maximum load Fm (N), bending stress (σ_b) (N/mm²), thickness (t) (mm), notch (N) (mm), energy (E) (Joule), impact price HI (joule/mm²).

Table 12. Pure resin specimen bending test data.

Specimens	L (mm)	T (mm)	N (mm)	E		A_p	HI
				Kg·cm	N·m (joule)	mm²	Joule/mm²
Pure Resin Composite	10	10	2	1.2	0.1177	80	0.00147

Table 13. Straight banana stem fiber specimen impact test data.

Specimens	L (mm)	T (mm)	N (mm)	E		A_p	HI
				Kg. mm	N·m (joule)	mm²	Joule /mm²
1 Layer Straight Fiber Press	10	10	2	2.6	0.25506	80	0.003188
1 Layer Vacuum Straight Fiber	10	10	2	3.7	0.36297	80	0.004537
2 Layers of Straight Fiber Press	10	10	2	2.6	0.25506	80	0.003188
2 Lapisan Serat Lurus Vakum	10	10	2	2.8	0.27468	80	0.003434

Table 14. Transverse banana stem fiber specimen impact test data.

Specimens	L (mm)	T (mm)	N (mm)	E		A_p	HI
				Kg.mm	N·m (joule)	mm²	Joule /mm²
1 Layer of Pressed Transverse Fiber	10	10	2	3.0	0.2943	80	0.003679
1 layer of vacuum transverse fiber	10	10	2	2.7	0.26487	80	0.003311
2 Layers of Vacuum Transverse Fiber	10	10	2	3.4	0.33354	80	0.004169
2 Layers of Vacuum Transverse Fiber	10	10	2	3.0	0.2943	80	0.003679

Table 15. Random banan stem fiber specimen impact test data.

Specimens	L (mm)	T (mm)	N (mm)	E		A_p	HI
				Kg.mm	N·m (joule)	mm²	Joule /mm²
1 Layer Random Fiber Press	10	10	2	1.8	0.17658	80	0.002207
1 Layer Vacuum Random Fiber	10	10	2	4.5	0.44145	80	0.005518
2 Layers of Random Fiber Press	10	10	2	1.4	0.13734	80	0.001717
2 Layers of Vacuum Random Fiber	10	10	2	1.9	0.18639	80	0.00233

Table 16. Fiberglass specimen impact test data.

Specimens	L (mm)	T (mm)	N (mm)	E		A_p	HI
				Kg.mm	N·m (joule)	mm²	Joule /mm²
1 Layer Fiberglass Press	10	10	2	3.5	0.34335	80	0.004292
1 Vacuum Fiberglass Layer	10	10	2	4.8	0.47088	80	0.005886
2 Layers of Fiberglass Press	10	10	2	12.7	1.24587	80	0.015573
2 Layers Vacuum Fiberglass	10	10	2	15.4	1.51074	80	0.018884

Based on the Chart of Impact Price (Joule/mm²) graph Fig. 11, it can be seen that the value of impact resistance varies significantly between specimens. Specimens with fiberglass fibers show the highest impact resistance value, particularly in the two-layer configuration with the vacuum method, which reaches approximately 0.019 Joules/mm². This shows that fiberglass is very effective in absorbing impact energy. In contrast, specimens with straight fiber and transverse fiber have low impact resistance values and are relatively uniform, in the range of 0.002–0.004 Joule/mm². Specimens with random fibers showed a slight improvement, but still below the performance of fiberglass. Interestingly, pure resin specimens (without fibers) showed low values, confirming that the presence of fibers is essential in improving impact resistance. Overall, the type of fiber has a great effect on impact performance.

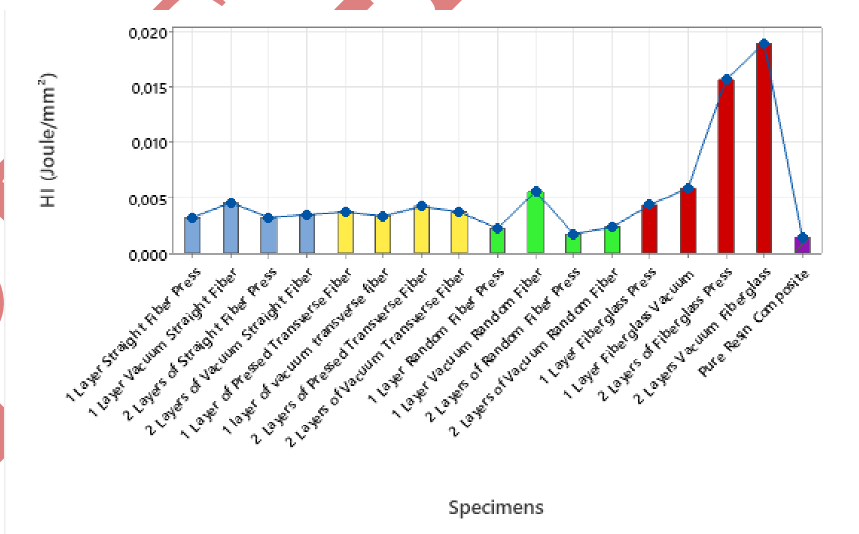


Figure 11. Chart of impact price.

4. CONCLUSION

Based on the experimental results and data analysis, it can be concluded that the 2-layer fiberglass composite fabricated using the vacuum method exhibited the highest tensile strength, with a maximum load of 3106 N. In the bending test, the composite with a 2-layer random fiber arrangement achieved the highest load-bearing capacity of 267.41 N. Furthermore, the impact test results indicated that the 2-layer composite with a random fiber arrangement demonstrated the greatest impact resistance, absorbing an energy of 15.4 kg·cm. These findings highlight the influence of fiber arrangement and fabrication method on the mechanical performance of fiberglass composites.

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