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Thermal Analysis of Natural Fiber and Hybrid Composites

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Abstract

This study examines how natural fiber and hybrid composites reinforced with natural and glass fibers perform under thermal conditions specifically, the effects of temperature that are common in automotive and aerospace environments. To evaluate their behavior, the composites were tested at two elevated temperatures, 60°C and 70°C. Mechanical tests such as tensile and impact were conducted to simulate real-world operating conditions and assess how thermal, and moisture exposure influence the materials' mechanical properties. At lower temperatures, the composites maintained good structural stability, retaining strength and stiffness. However, as temperature increased, a noticeable decline in performance was observed. The materials began to show signs of degradation, including reduced strength and lower stiffness. These results reveal the limitations of natural fiber composites when subjected to more demanding environments over time. The broader aim of this research is to better understand how these sustainable materials hold up in long-term service conditions. As industries look for greener alternatives to traditional composites, particularly in high-performance fields like aerospace and automotive engineering, it becomes crucial to assess both their strengths and weaknesses. By identifying where improvements are needed, this hygrothermal analysis supports the development of eco-friendly composite materials that can offer durability and reliability without compromising safety or performance.

Keywords: Glass fiber, hemp fiber, impact energy, linen fiber, tensile strength

INTRODUCTION

The growing demand for sustainable and high-performance materials in engineering applications has led to increased research into natural fiber and hybrid composites. These materials offer advantages such as low density, biodegradability, and reduced environmental impact, making them attractive for use in the construction, automotive, and aerospace industries. In case of natural fiber and hybrid composites, thermal analysis is crucial because natural fibers (hemp, linen, etc.) begin to degrade when exposed to higher temperatures. For safety and reliability, it is essential to know the behavior of these composites when applications involve exposures to higher temperatures. Natural fibers like hemp, flax, and jute have been widely investigated for their mechanical properties and eco-friendly nature. However, their long-term reliability under varying environmental conditions, especially in hygrothermal environments, remains a concern. Natural fibers generally begin to thermally degrade at lower temperatures compared to synthetic fibers. Natural fibers are hydrophilic and absorb moisture from the environment, which evaporates at lower temperatures, affecting dimensional stability and initial thermal performance. Synthetic fibers are usually hydrophobic and more dimensionally stable under heat.

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The understanding of hygrothermal analysis in composite materials has been brought forward by Asim Shahzad [1], Nachippan and N. Murugu [2], Yuanjian and D. H. Isaac [3], Dhakal [4]; hemp, flax, and jute are some of the natural fiber composites that have been studied for their sustainable nature and their application in the building, automotive, and aerospace industries. Nevertheless, their durability and structural integrity rely on their performance in hygrothermal environments. The objective of hybrid composites is to mitigate these issues by combining natural and synthetic fibers. Mejri et al[5]. and Osman et al[6]. have demonstrated that long-term exposure to humid and high-temperature conditions can change mechanical performance, resulting in fatigue failure and reduced structural efficiency. Chau et al[7]. and Zhang et al[8]. have studied hygrothermal effects in aerospace composite structures. Poupard et al[9]. studied the hygrothermal characteristics of hemp concrete, demonstrating material shrinkage and variations in thermal conductivity. Colinart et al[10]., Garg et al[11]., and Neto et al[12]. have also made contributions to the mechanical characterization of natural fiber composites. Tsai et al[13]. and Asim et al[14]. studied the thermal stability of natural fiber and hybrid composites. Kudva et al[15]. analyzed the temperature effect on vibration behavior of natural fiber and hybrid composites. Sumesh K. R. et al[16]. analyzed the natural and glass fibers reinforced into an epoxy matrix composite and found that significant improvement in tensile, flexure, and impact strength with alkali-treated areca fibers (20 wt%) and glass fibers (20 wt%). Palanisamy S. et al[17]. investigated the properties of Acacia caesia bark fibers (ACBFs), highlighting their potential as natural reinforcements in polymer composites. The study provided detailed characterization including physical, chemical, and mechanical behavior. Almeshaal et al[18]. performed a physicochemical characterization of Grewia Monticola Sond (GMS) fibers, exploring their suitability for use in biocomposite applications. Palaniappan et al[19]. introduced Ficus retusa L. aerial root fiber as a novel, sustainable reinforcement alternative to synthetic fibers in polymer composites. The study highlighted its mechanical, thermal, and morphological properties suitable for eco-friendly composite applications. Palanisamy et al[20]. tailored epoxy composites using Acacia caesia bark fibers, analyzing how variations in fiber content and length affect composite properties. The study revealed significant improvements in mechanical performance with optimized fiber parameters. Palanisamy et al[21]. evaluated the mechanical and wear performance of natural fiber-reinforced epoxy composites. The results demonstrated enhanced strength and wear resistance, supporting their potential use in structural and industrial applications. Palanisamy et al[22]. investigated the wear properties and post-moisture absorption mechanical behavior of kenaf/banana fiber-reinforced epoxy composites. The study showed that fiber hybridization and moisture exposure significantly influence composite durability and performance. The study demonstrated promising mechanical and structural properties of GMS fibers for sustainable material development. To optimize composite materials for real applications, one must know how mechanical properties, moisture, and temperature interact. This paper reviews the mechanisms of hygrothermal aging, thermal degradation, and moisture diffusion in hybrid and natural fiber composites, providing a comprehensive review of recent advances in this area.

METHODOLOGY

Selection of Materials

For this investigation, three different kinds of reinforcing fibers were used: glass fiber, which is synthetic; hemp and linen, which are natural; and a hybrid configuration that incorporates both natural and synthetic fibers. Because of their exceptional durability and bonding properties, high-strength thermosetting epoxy (LY556) and hardener (HY951) were used as matrix material for all samples.

Sample Fabrication

The fabrication process began with the preparation of the fiber mat. First, natural fibers (linen and hemp) were cleaned to remove impurities and improve fiber-matrix interfacial contact. After being cleaned and dried, the natural fibers were ready for lay-up. For synthetic fibers that required no additional processing, glass fiber mats were used. To provide a balanced foundation for hybrid composites, layers of natural and synthetic fibers were alternatively placed, optimizing mechanical performance and sustainability.

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Vacuum Bagging Process

Composite laminates were made by vacuum bagging technique, which ensured better consolidation and less void content. Epoxy (LY556) and Hardener (HY951) resin were placed uniformly between fiber mat layers following the use of a mold release agent. After sealing the lay-up stack in a vacuum bag, vacuum pressure was applied. This promoted even resin dispersion, enhanced fiber wetting, and eliminated trapped air. For full curing, the vacuum pressure was kept at room temperature for four to five hours. Following curing, the laminates were carefully taken out of the mold and cut to standard sample dimensions with a precision cutting machine. By reducing flaws and increasing fiber-matrix adhesion, this technique improved laminate quality.

Specimen Preparation

Specimens for mechanical testing were cut from the laminates according to following ASTM standards:

- *Tensile test specimens:* Prepared according to ASTM D3039 (250 mm × 25 mm)
- *Impact test specimens:* Prepared as per ASTM D7136 (150 mm × 100 mm)

RESULTS

Tensile Testing at Room Temperature

Tensile testing of composite specimens was performed according to ASTM D3039 standards. The specimens had a width of 25 mm, an overall length of 250 mm, and a gauge length of 150 mm. A Universal Testing Machine (UTM) with a load capacity of 1000 kN was used for the test. This setup ensured precise measurement of tensile strength and deformation behavior. The test results provide valuable insight into the mechanical properties of the hemp material under axial loading.

Hemp Fiber Composites

The tensile test samples fabricated by using hemp fibers with four layers arranged symmetrically in a [0°/0°]s and [90°/90°]s orientations as shown in Figure 1. The results for along and across orientations of fiber samples are tabulated in Table 1, and the graphs are presented in Figure 2.

From the results, we observed that the peak load was higher when the fibers were aligned in the direction of the applied load, compared to when the fibers were perpendicular to the load. This indicates that aligning the fibers along the direction of the load leads to better strength performance, making it the more effective and preferred orientation for the material.

Figure 1. Hemp fiber composite specimens for tensile test at room temperature.

Linen Fiber Composites

The tensile test samples fabricated by using linen fibers with six layers arranged symmetrically in a [0°/0°/0°]s and [90°/90°/90°]s orientations as shown in Figure 3. The results for along and across orientations of fiber samples are tabulated in Table 2, and the graphs are presented in Figure 4.

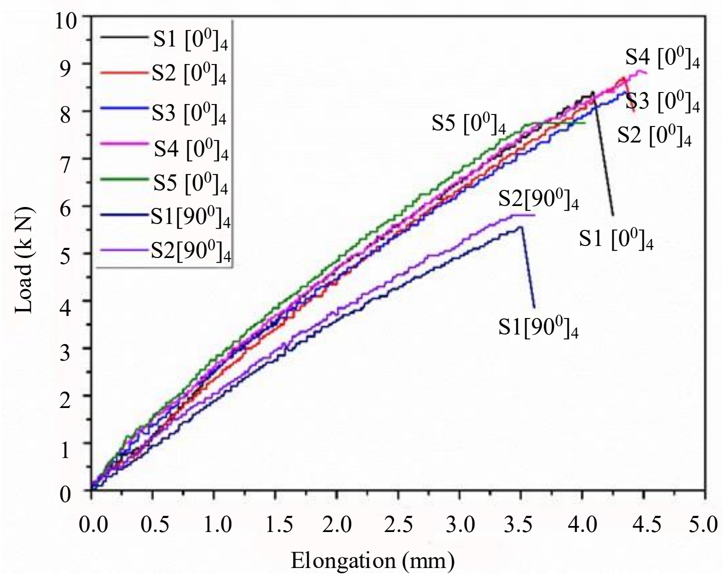

Figure 2. Tensile test results of hemp fiber composite specimens at room temperature.

Table 1. Tensile test results for 4 layered hemp fiber composite samples at room temperature.

Fiber orientation	Sample	Thickness (mm)	Load at peak (kN)	Elongation at peak (mm)
$[0^0/0^0]$s	1	3.95	8.850	4.470
$[0^0/0^0]$s	2	3.74	8.650	4.360
$[0^0/0^0]$s	3	3.86	8.300	4.100
$[0^0/0^0]$s	4	3.91	8.400	4.320
$[0^0/0^0]$s	5	3.95	7.700	3.350
$[90^0/90^0]$s	1	3.99	5.820	3.420
$[90^0/90^0]$s	2	3.90	5.700	3.350

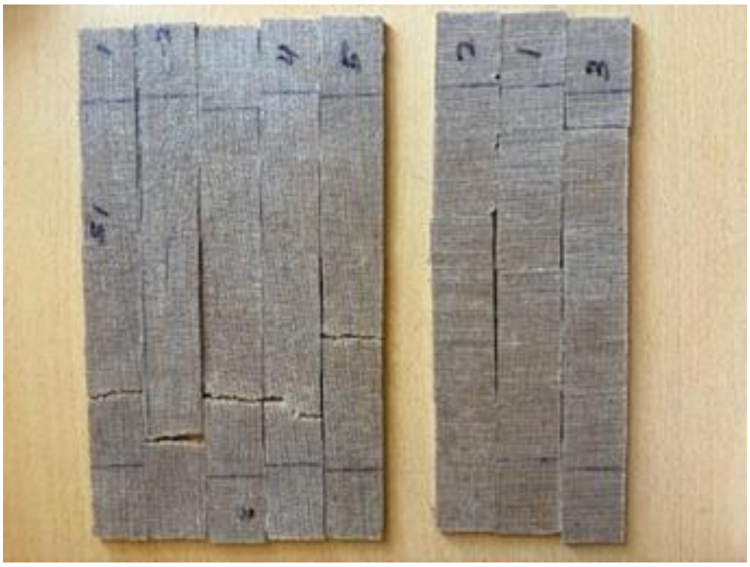

Figure 3. Linen fiber composite specimens for tensile test at room temperature.

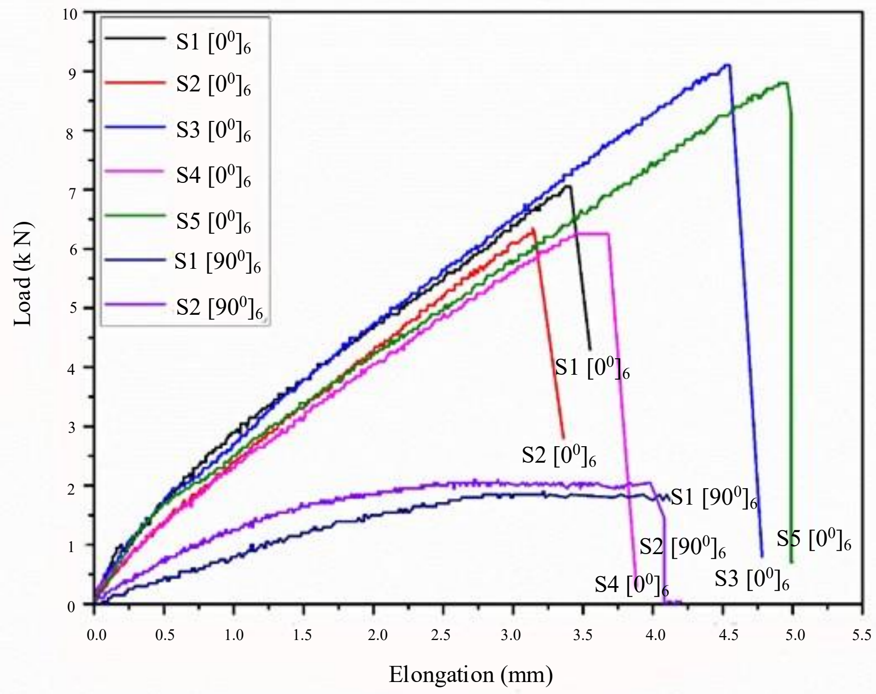

Figure 4. Tensile test results of linen fiber composite specimens at room temperature.

Table 2. Tensile test results for 6 layered linen fiber composite samples at room temperature.

Fiber orientation	Sample	Thickness (mm)	Load at peak (kN)	Elongation at peak (mm)
$[0^0/0^0/0^0]$s	1	4.15	7.050	3.470
$[0^0/0^0/0^0]$s	2	4.20	6.350	3.150
$[0^0/0^0/0^0]$s	3	4.10	9.100	4.590
$[0^0/0^0/0^0]$s	4	4.22	6.250	3.810
$[0^0/0^0/0^0]$s	5	4.18	8.800	4.990
$[90^0/90^0/90^0]$s	1	4.10	1.900	3.230
$[90^0/90^0/90^0]$s	2	3.90	2.100	3.330

From the results, we observed that the peak load was higher when the fibers were aligned in the direction of the applied load, compared to when the fibers were perpendicular to the load.

Hybrid Hemp and Glass Fiber Composites

The tensile test samples fabricated by using hemp and glass fibers with four layers arranged symmetrically in a [0°/0°]s and [90°/90°]s orientations as shown in Figure 5. The results for along and across orientations of fiber samples are tabulated in Table 3, and the graphs are presented in Figure 6.

Figure 5. Hybrid hemp and glass fiber composite specimens for tensile test at room temperature.

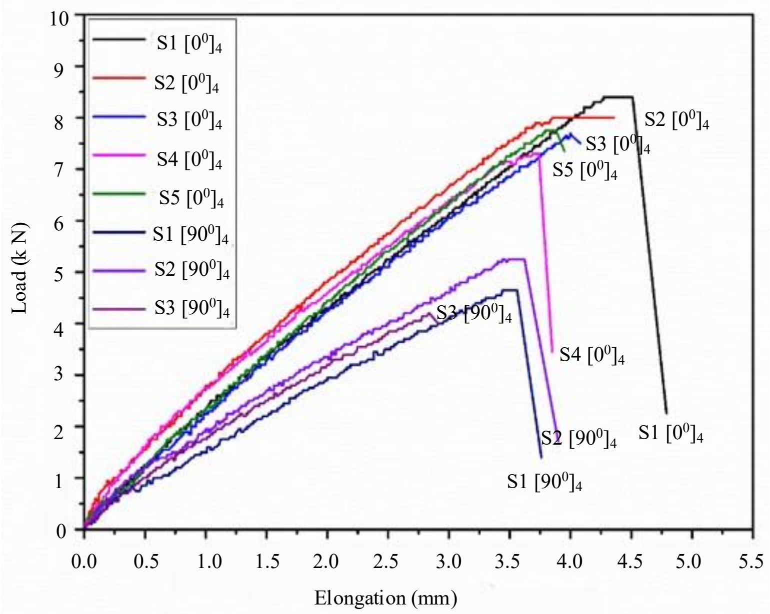

Figure 6. Tensile test results of hybrid hemp and glass fiber composite specimens at room temperature.

Table 3. Tensile test results for 4 layered hybrid hemp and glass fiber composite samples at room temperature.

Fiber orientation	Sample	Thickness (mm)	Load at peak (kN)	Elongation at peak (mm)
[0^0/0^0]s	1	2.70	8.400	4.660
[0^0/0^0]s	2	2.56	8.000	4.490
[0^0/0^0]s	3	2.50	7.700	4.010
[0^0/0^0]s	4	2.45	7.300	3.780
[0^0/0^0]s	5	2.56	7.750	3.900
[90^0/90^0]s	1	2.65	4.650	3.640
[90^0/90^0]s	2	2.54	5.250	3.740
[90^0/90^0]s	3	2.52	4.200	2.850

The results indicates that aligning the fibers along the direction of the load leads to better strength performance, making it the more effective and preferred orientation for the material.

Hybrid Linen and Glass Fiber Composites

The tensile test samples fabricated by using linen and glass fibers with six layers arranged symmetrically in a [0°/0°/0°]s and [90°/90°/90°]s orientations as shown in Figure 7. The results for along and across orientations of fiber samples are tabulated in Table 4, and the graphs are presented in Figure 8.

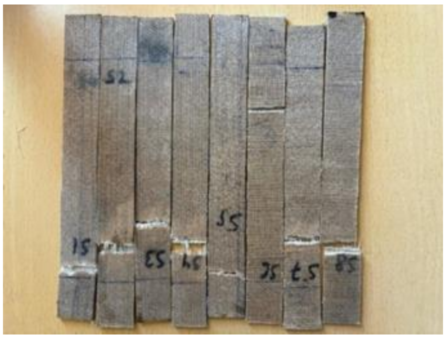

Figure 7. Hybrid linen and glass fiber composite specimens for tensile test at room temperature.

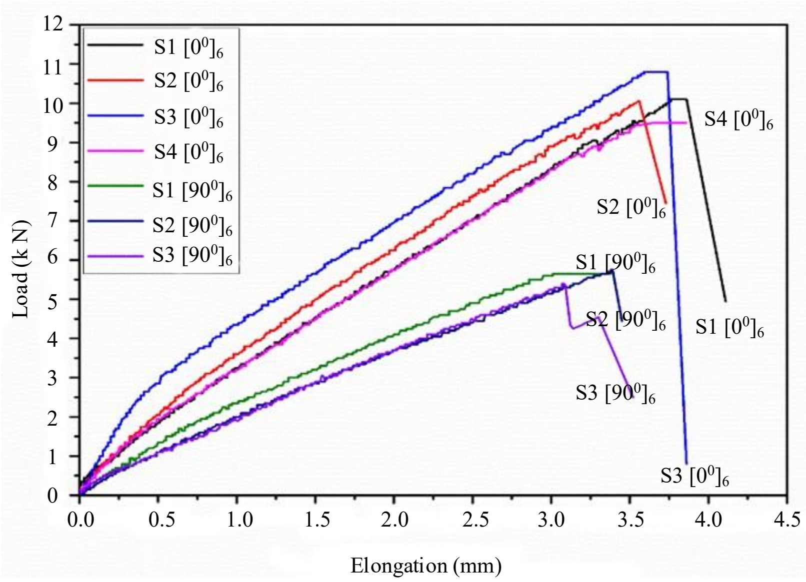

Figure 8. Tensile test results of hybrid linen and glass fiber composite specimens at room temperature.

Table 4. Tensile test results for 6 layered hybrid linen and glass fiber composite samples at room temperature.

Fiber orientation	Sample	Thickness (mm)	Load at peak (kN)	Elongation at peak (mm)
$[0^0/0^0/0^0]$s	1	3.90	10.100	3.970
$[0^0/0^0/0^0]$s	2	4.10	10.050	3.620
$[0^0/0^0/0^0]$s	3	3.85	10.800	3.800
$[0^0/0^0/0^0]$s	4	3.92	9.500	3.980
$[0^0/0^0/0^0]$s	5	4.10	9.400	3.900
$[90^0/90^0/90^0]$s	1	3.89	5.650	3.580
$[90^0/90^0/90^0]$s	2	3.96	5.750	3.400
$[90^0/90^0/90^0]$s	3	4.05	5.400	3.090

From the results, we observed that the peak load was higher when the fibers were aligned in the direction of the applied load, compared to when the fibers were perpendicular to the load.

Impact Testing at Room Temperature

Drop weight impact tests were conducted on both natural and hybrid fiber composites following ASTM D7136 standards. Specimens measuring 100 mm by 150 mm were used to simulate real world low-velocity impact conditions. The test helped assess the materials ability to absorb energy and resist damage. These results offer useful insights into their toughness and suitability for structural applications.

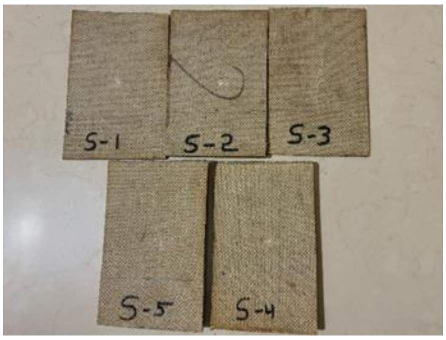

Figure 9. Hemp fiber composite specimens for impact test at room temperature.

Hemp Fiber Composites

Impact test samples made from hemp fibers, arranged in four cross ply oriented layers [0°/90°]s, were tested using a drop weight setup. In this test, a weight was dropped from different heights onto the samples as shown in Figure 9, and the results are shown in Table 5.

As the drop height increased, the samples absorbed more energy. This shows a direct link between the height of the drop and the material's ability to absorb impact.

Linen Fiber Composites

Impact test samples made from linen fibers, arranged in six symmetrical cross ply layers [0°/90°/0°]s, were tested using a drop weight setup. In this test, a weight was dropped from different heights onto the samples as shown in Figure 10, and the results are tabulated in Table 6.

As the drop height increased, the samples absorbed more energy. This shows a direct link between the impact energy and the material's ability to absorb impact. Instead of breaking right away, the material developed tiny cracks and internal changes that helped spread out the force and absorb the energy, making it more resistant to sudden failure.

Hybrid Hemp and Glass Fiber Composites

Impact test samples made from hemp and glass fibers, arranged in four symmetrical cross ply layers [0°/90°]s, were tested using a drop weight setup. In this test, a weight was dropped from different heights onto the samples as shown in Figure 11, and the results are tabulated in Table 7.

Table 5. Impact test results for 4 layered hemp fiber composite samples at room temperature.

Sample	Height (m)	Impact energy (J)	Energy absorbed (J)	Velocity (m/s)
1	0.05	3.301	1.206	0.990
2	0.08	5.281	1.830	1.252
3	0.10	6.602	2.863	1.400
4	0.12	7.922	3.308	1.534
5	0.14	9.242	4.662	1.657

Figure 10. Linen fiber composite specimens for impact test at room temperature.

Table 6. Impact test results for 6 layered linen fiber composite samples at room temperature.

Sample	Height (m)	Impact energy (J)	Energy absorbed (J)	Velocity (m/s)
1	0.05	3.301	1.293	0.990
2	0.08	5.281	1.811	1.252
3	0.10	6.602	1.778	1.400
4	0.12	7.922	2.346	1.534
5	0.14	9.242	3.570	1.657

Figure 11. Hybrid hemp and glass fiber composite specimens for impact test at room temperature.

Table 7. Impact test results for 4 layered hybrid hemp and glass fiber composite samples at room temperature.

Sample	Height (m)	Impact energy (J)	Energy absorbed (J)	Velocity (m/s)
1	0.05	3.301	1.619	0.990
2	0.08	5.281	2.080	1.252
3	0.10	6.602	2.437	1.400
4	0.12	7.922	2.523	1.534
5	0.14	9.242	3.243	1.657

The results shows a direct link between the height of the drop and the material's ability to absorb impact.

Hybrid Linen and Glass Fiber Composites

Impact test samples made from linen and glass fibers, arranged in six symmetrical cross ply layers [0°/90°/0°]s, were tested using a drop weight setup. In this test, a weight was dropped from different heights onto the samples as shown in Figure 12, and the results are shown in Table 8.

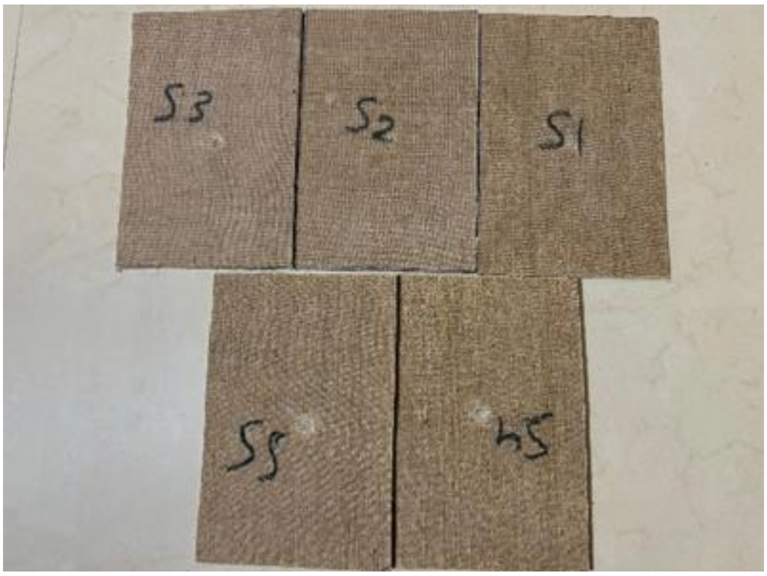

Figure 12. Hybrid linen and glass fiber composite specimens for impact test at room temperature.

Table 8. Impact test results for 6 layered hybrid linen and glass fiber composite samples at room temperature.

Sample	Height (m)	Impact energy (J)	Energy absorbed (J)	Velocity (m/s)
1	0.05	3.301	1.342	0.990
2	0.08	5.281	2.154	1.252
3	0.10	6.602	2.328	1.400
4	0.12	7.922	2.645	1.534
5	0.14	9.242	2.758	1.657

As the drop height increased, the samples absorbed more energy. This shows a direct link between the height of the drop and the material's ability to absorb impact.

Tensile Testing at 60°C Temperature

Hemp fiber composites

The tensile test samples fabricated by using hemp fibers with four layers arranged symmetrically in a [0°/0°]s and [90°/90°]s orientations as shown in Figure 13. The samples were kept at 60°C temperature for 15 days. The results for along and across orientations of fiber samples are tabulated in Table 9 and the graphs are presented in Figure 14.

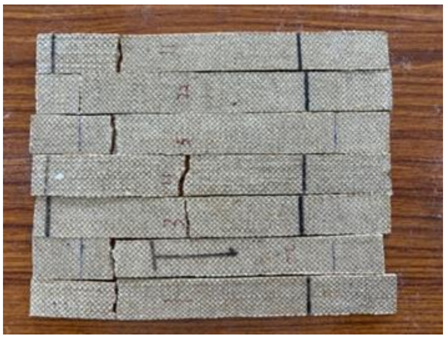

Fig 13. Hemp fiber composite specimens for tensile test at 60°c temperature.

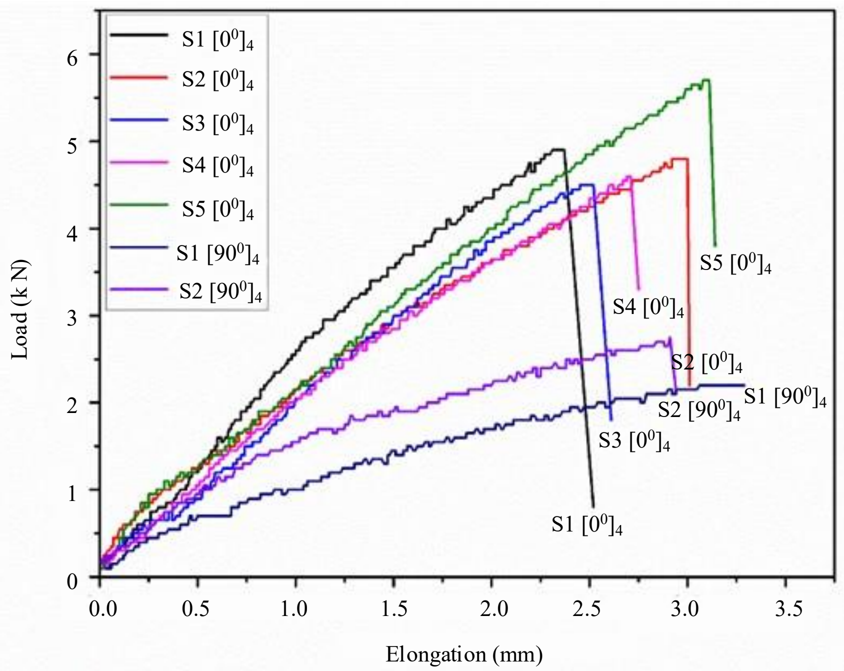

Figure 14. Tensile test results of hemp fiber composite specimens at 60°c temperature.

Table 9. Tensile test results for 4 layered hemp fiber composite samples at 60°c temperature.

Fiber orientation	Sample	Thickness (mm)	Load at peak (kN)	Elongation at peak (mm)
$[0^0/0^0]$s	1	3.92	4.900	2.440
$[0^0/0^0]$s	2	3.86	5.400	3.010
$[0^0/0^0]$s	3	3.90	4.500	2.560
$[0^0/0^0]$s	4	3.91	4.600	2.730
$[0^0/0^0]$s	5	3.94	5.700	3.130
$[90^0/90^0]$s	1	3.98	2.200	3.420
$[90^0/90^0]$s	2	3.89	2.750	2.920

From the results, we observed that the peak load was higher when the fibers were aligned in the direction of the applied load, compared to when the fibers were perpendicular to the load.

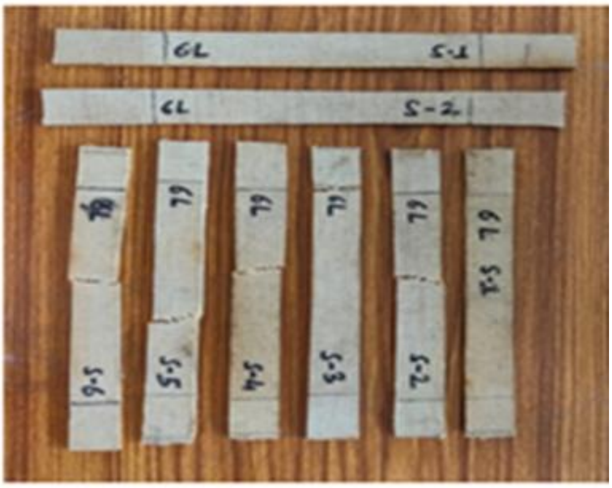

Figure 15. Linen fiber composite specimens for tensile test at 60°c temperature.

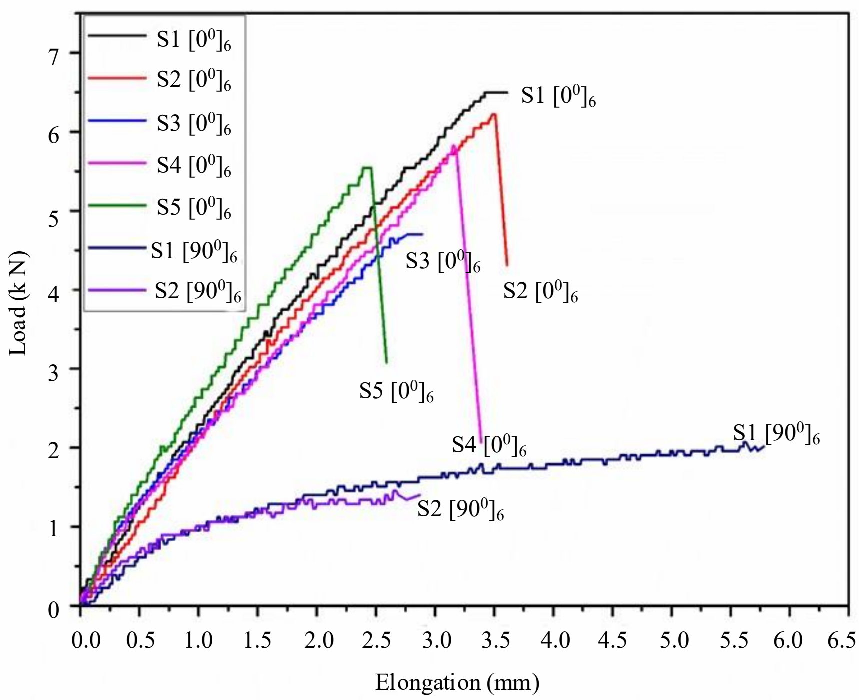

Figure 16. Tensile test results of linen fiber composite specimens at 60°c temperature.

Linen Fiber Composites

The tensile test samples fabricated by using linen fibers with six layers arranged symmetrically in a [0°/0°/0°]s and [90°/90°/90°]s orientations as shown in Figure 15. The samples were kept at 60°C temperature for 15 days. The results for along and across orientations of fiber samples are tabulated in Table 10 and the graphs are presented in Figure 16.

The results indicates that aligning the fibers along the direction of the load leads to better strength performance, making it the more effective and preferred orientation for the material.

Table 10. Tensile test results for 6 layered linen fiber composite samples at 60°c temperature.

Fiber orientation	Sample	Thickness (mm)	Load at peak (kN)	Elongation at peak (mm)
$[0^0/0^0/0^0]$s	1	4.15	6.450	3.270
$[0^0/0^0/0^0]$s	2	4.20	6.220	3.255
$[0^0/0^0/0^0]$s	3	4.10	5.670	3.095
$[0^0/0^0/0^0]$s	4	4.22	5.550	2.650
$[0^0/0^0/0^0]$s	5	4.18	4.570	2.250
$[90^0/90^0/90^0]$s	1	4.10	1.920	5.750
$[90^0/90^0/90^0]$s	2	3.90	1.230	2.750

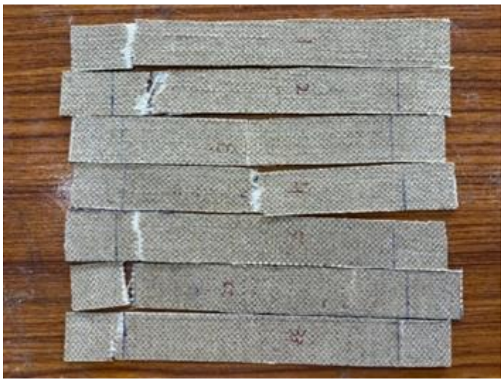

Figure 17. Hybrid hemp and glass fiber composite specimens for tensile test at 60°c temperature.

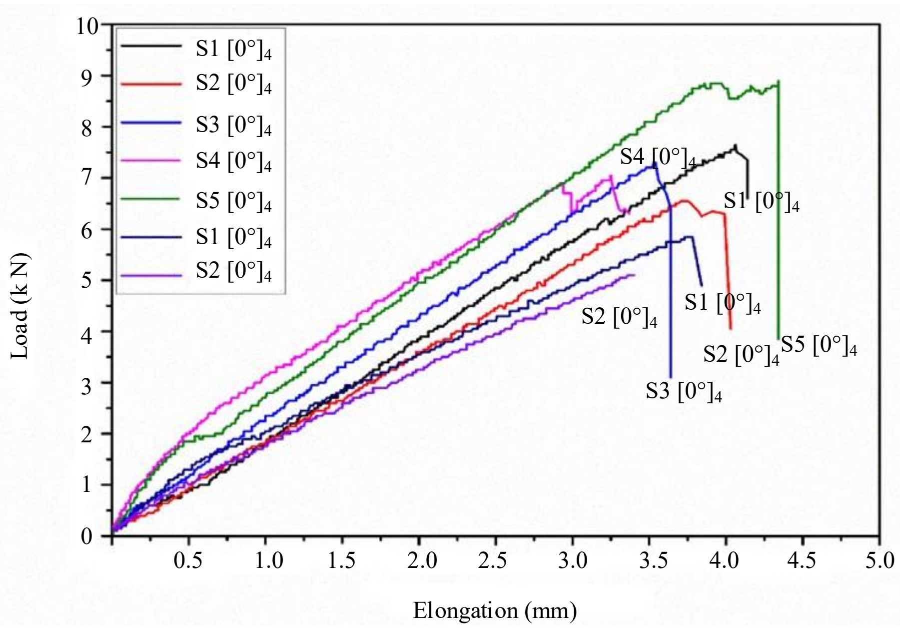

Figure 18. Tensile test results of hybrid hemp and glass fiber composite specimens at 60°c temperature.

Hybrid Hemp and Glass Fiber Composites

The tensile test samples fabricated by using hemp and glass fibers with four layers arranged symmetrically in a [0°/0°]s and [90°/90°]s orientations as shown in Figure 17. The samples were kept at 60°C temperature for 15 days. The results for along and across orientations of fiber samples are tabulated in Table 11, and the graphs are presented in Figure 18.

From the results, we observed that the peak load was higher when the fibers were aligned in the direction of the applied load, compared to when the fibers were perpendicular to the load.

Hybrid Linen and Glass Fiber Composites

The tensile test samples fabricated by using linen and glass fibers with six layers arranged symmetrically in a [0°/0°/0°]s and [90°/90°/90°]s orientations as shown in Figure 19. The samples were kept at 60°C temperature for 15 days. The results for along and across orientations of fiber samples are tabulated in Table 12, and the graphs are presented in Figure 20.

Table 11. Tensile test results for 4 layered hybrid hemp and glass fiber composite samples at 60°c temperature.

Fiber orientation	Sample	Thickness (mm)	Load at peak (kN)	Elongation at peak (mm)
$[0^0/0^0]$s	1	2.70	7.650	4.070
$[0^0/0^0]$s	2	2.56	6.550	3.760
$[0^0/0^0]$s	3	2.50	7.300	3.550
$[0^0/0^0]$s	4	2.45	7.050	3.260
$[0^0/0^0]$s	5	2.56	8.900	4.340
$[90^0/90^0]$s	1	2.65	5.850	3.790
$[90^0/90^0]$s	2	2.54	5.100	3.410
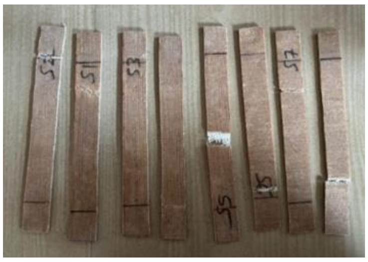
Figure 19. Hybrid linen and glass fiber composite specimens for tensile test at 60°c temperature.

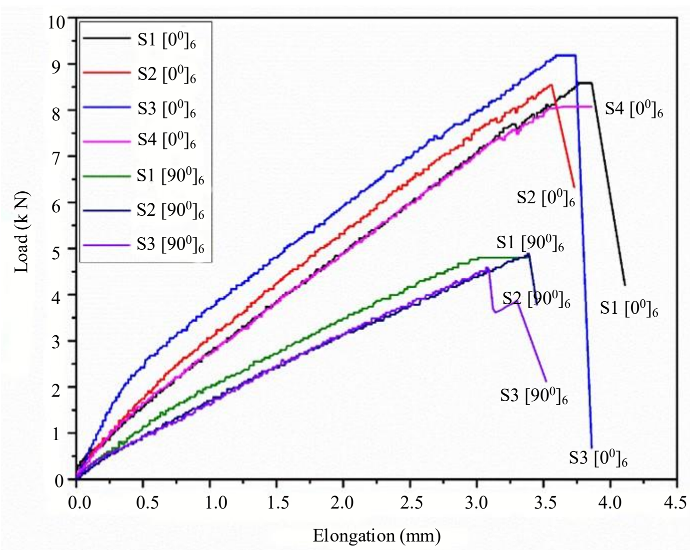

Figure 20. Tensile test results of hybrid linen and glass fiber composite specimens at 60°c temperature.

Table 12. Tensile test results for 6 layered hybrid linen and glass fiber composite samples at 60°c temperature.

Fiber orientation	Sample	Thickness (mm)	Load at peak (kN)	Elongation at peak (mm)
$[0^0/0^0/0^0]$s	1	3.90	9.250	3.620
$[0^0/0^0/0^0]$s	2	4.10	8.560	3.520
$[0^0/0^0/0^0]$s	3	3.85	8.500	3.980
$[0^0/0^0/0^0]$s	4	3.92	7.850	3.480
$[90^0/90^0/90^0]$s	1	4.10	4.750	3.300
$[90^0/90^0/90^0]$s	2	3.89	4.620	3.100
$[90^0/90^0/90^0]$s	3	3.96	4.450	2.900

The results indicates that aligning the fibers along the direction of the load leads to better strength performance, making it the more effective and preferred orientation for the material.

Impact Testing at 60°C Temperature

Hemp fiber composites

Impact test samples made from hemp fibers, arranged in four cross ply oriented layers [0°/90°]s, were tested using a drop weight setup as shown in Figure 21. The samples were kept at 60°C temperature for 15 days. In this test, a weight was dropped from different heights onto the samples, and the results are shown in Table 13.

The results shows a direct link between the height of the drop and the material's ability to absorb impact.

Linen Fiber Composites

Impact test samples made from hemp fibers, arranged in six cross ply oriented layers [0°/90°/0°]s, were tested using a drop weight setup as shown in Figure 22. The samples were kept at 60°C temperature for 15 days. In this test, a weight was dropped from different heights onto the samples, and the results are shown in Table 14.

Figure 21. Hemp fiber composite specimens for impact test at 60°c temperature.

Table 13. Impact test results for 4 layered hemp fiber composite samples at 60°c temperature.

Sample	Height (m)	Impact energy (J)	Energy absorbed (J)	Velocity (m/s)
1	0.05	3.301	1.754	0.990
2	0.08	5.281	2.563	1.252
3	0.10	6.602	3.350	1.400
4	0.12	7.922	3.850	1.534
5	0.14	9.242	4.452	1.657

Figure 22. Linen fiber composite specimens for impact test at 60°c temperature.

Table 14. Impact test results for 6 layered linen fiber composite samples at 60°c temperature.

Sample	Height (m)	Impact energy (J)	Energy absorbed (J)	Velocity (m/s)
1	0.05	3.301	1.254	0.990
2	0.08	5.281	1.795	1.252
3	0.10	6.602	1.985	1.400
4	0.12	7.922	2.654	1.534
5	0.14	9.242	3.215	1.657

From the results we can see that as the drop height increased, the samples absorbed more energy.

Hybrid Hemp and Glass Fiber Composites

Impact test samples made from hemp and glass fibers, arranged in four cross ply oriented layers [0°/90°]s, were tested using a drop weight setup as shown in Figure 23. The samples were kept at 60°C temperature for 15 days. In this test, a weight was dropped from different heights onto the samples, and the results are shown in Table 15.

Figure 23. Hybrid hemp and glass fiber composite specimens for impact test at 60°c temperature.

Table 15. Impact test results for 4 layered hybrid hemp and glass fiber composite samples at 60°c temperature.

Sample	Height (m)	Impact energy (J)	Energy absorbed (J)	Velocity (m/s)
1	0.05	3.301	1.512	0.990
2	0.08	5.281	1.956	1.252
3	0.10	6.602	2.550	1.400
4	0.12	7.922	3.056	1.534
5	0.14	9.242	3.357	1.657

Figure 24. Hybrid linen and glass fiber composite specimens for impact test at 60°c temperature.

Table 16. Impact test results for 6 layered hybrid linen and glass fiber composite samples at 60°c temperature.

Sample	Height(m)	Impact energy (J)	Energy absorbed (J)	Velocity(m/s)
1	0.05	3.301	1.424	0.990
2	0.08	5.281	1.671	1.252
3	0.10	6.602	2.556	1.400
4	0.12	7.922	3.373	1.534
5	0.14	9.242	3.442	1.657

As the drop height increased, the samples absorbed more energy. This shows a direct link between the height of the drop and the material's ability to absorb impact. In simple terms, the higher the drop, the better the material was at taking the hit. Instead of breaking right away, the material developed tiny cracks and internal changes that helped spread out the force and absorb the energy, making it more resistant to sudden failure.

Hybrid Linen and Glass Fiber Composites

Impact test samples made from linen and glass fibers, arranged in six cross ply oriented layers [0°/90°/0°]s, were tested using a drop weight setup as shown in Figure 24. The samples were kept at 60°C temperature for 15 days. In this test, a weight was dropped from different heights onto the samples, and the results are shown in Table 16.

As the drop height increased, the samples absorbed more energy. This shows a direct link between the height of the drop and the material's ability to absorb impact.

Tensile Testing at 70°C Temperature

Hemp fiber composites

The tensile test samples fabricated by using linen fibers with four layers arranged symmetrically in a [0°/0°]s and [90°/90°]s orientations as shown in Figure 25. The samples were kept at 70°C temperature for 15 days. The results for along and across orientations of fiber samples are tabulated in Table 17 and the graphs are presented in Figure 26.

Figure 25. Hemp fiber composite specimens for tensile test at 70°c temperature.

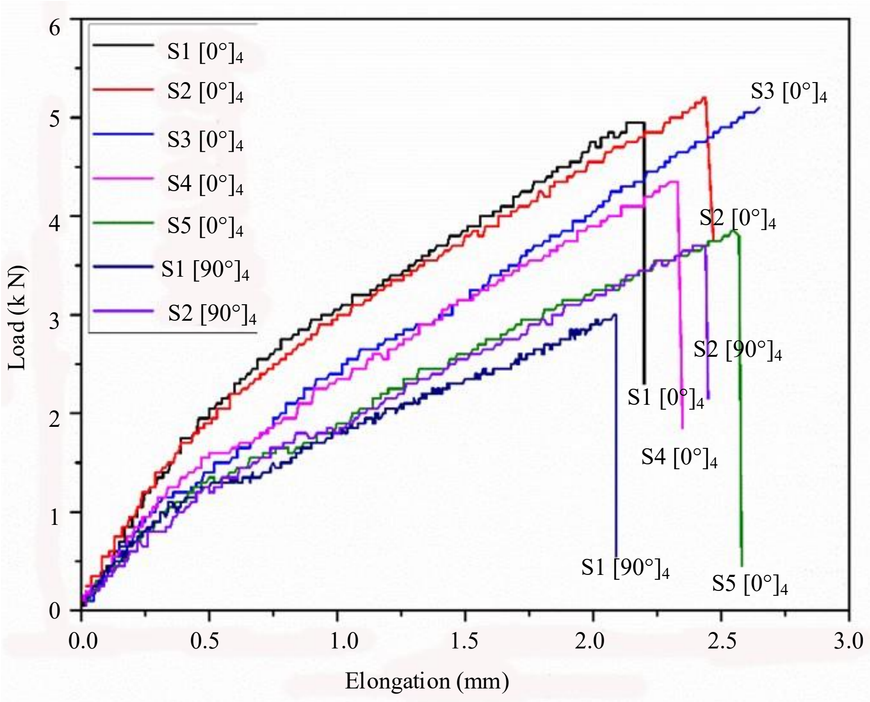

Figure 26. Tensile test results of hemp fiber composite specimens at 70°c temperature.

Table 17. Tensile test results for 4 layered hemp fiber composite samples at 70°c temperature.

Fiber orientation	Sample	Thickness (mm)	Load at peak (kN)	Elongation at peak (mm)
$[0^0/0^0]$s	1	3.98	5.150	2.600
$[0^0/0^0]$s	2	3.86	5.010	2.400
$[0^0/0^0]$s	3	3.94	4.900	2.550
$[0^0/0^0]$s	4	3.91	4.300	2.450
$[0^0/0^0]$s	5	3.95	3.750	2.330
$[90^0/90^0]$s	1	3.99	3.600	2.220
$[90^0/90^0]$s	2	3.92	3.100	2.130

From the results, we observed that the peak load was higher when the fibers were aligned in the direction of the applied load, compared to when the fibers were perpendicular to the load.

Linen Fiber Composites

The tensile test samples fabricated by using linen fibers with six layers arranged symmetrically in a [0°/0°/0°]s and [90°/90°/90°]s orientations as shown in Figure 27. The samples were kept at 70°C temperature for 15 days. The results for along and across orientations of fiber samples are tabulated in Table 18 and the graphs are presented in Figure 28.

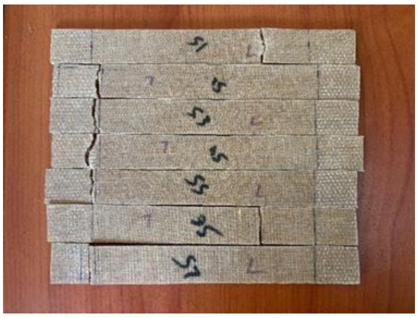

Figure 27. Linen fiber composite specimens for tensile test at 70°c temperature.

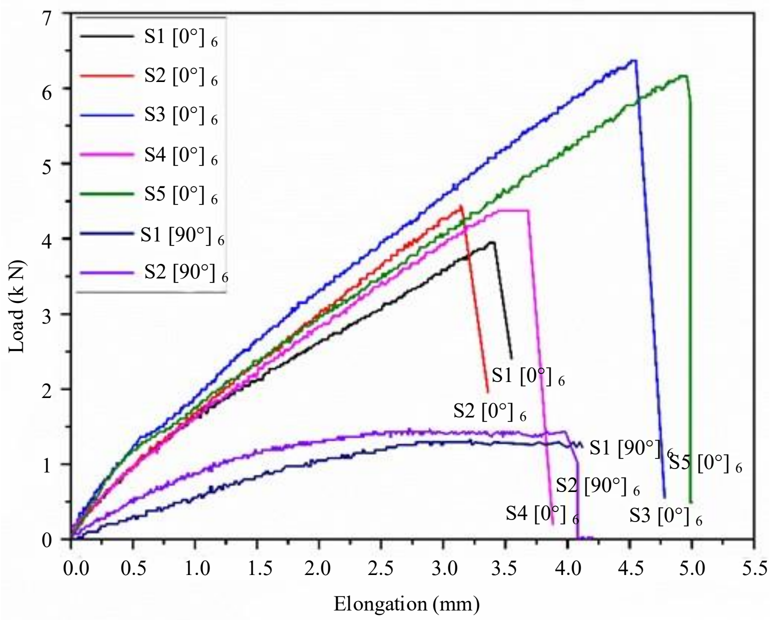

Figure 28. Tensile test results of linen fiber composite specimens at 70°c temperature.

Table 18. Tensile test results for 6 layered linen fiber composite samples at 70°c temperature.

Fiber orientation	Sample	Thickness (mm)	Load at peak (kN)	Elongation at peak (mm)
$[0^0/0^0]$s	1	3.98	5.150	2.600
$[0^0/0^0]$s	2	3.86	5.010	2.400
$[0^0/0^0]$s	3	3.94	4.900	2.550
$[0^0/0^0]$s	4	3.91	4.300	2.450
$[0^0/0^0]$s	5	3.95	3.750	2.330
$[90^0/90^0]$s	1	3.99	3.600	2.220
$[90^0/90^0]$s	2	3.92	3.100	2.130

From the results, we observed that the peak load was higher when the fibers were aligned in the direction of the applied load, compared to when the fibers were perpendicular to the load. This indicates that aligning the fibers along the direction of the load leads to better strength performance, making it the more effective and preferred orientation for the material.

Hybrid Hemp and Glass Fiber Composites

The tensile test samples fabricated by using hemp and glass fibers with four layers arranged symmetrically in a [0°/0°]s and [90°/90°]s orientations as shown in Figure 29. The samples were kept at 70°C temperature for 15 days. The results for along and across orientations of fiber samples are tabulated in Table 19 and the graphs are presented in Figure 30.

Figure 29. Hybrid hemp and glass fiber composite specimens for tensile test at 70°c temperature.

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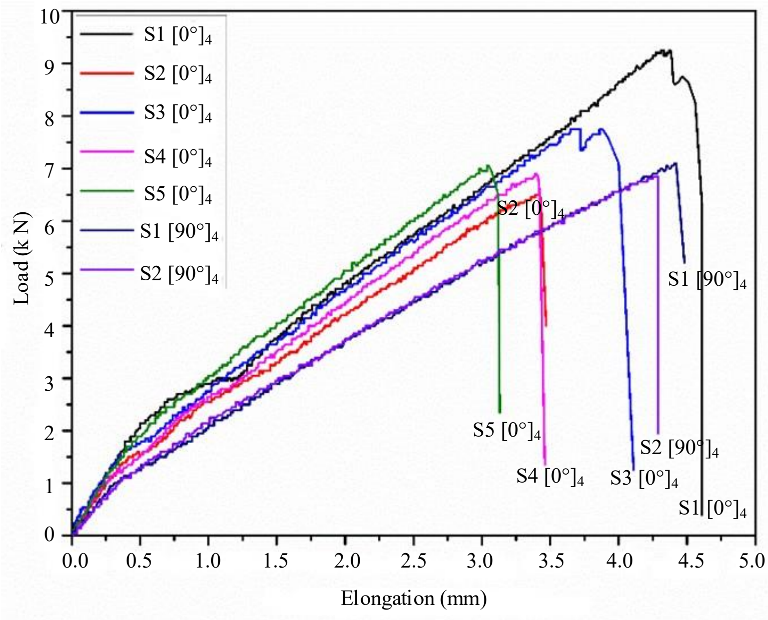

Figure 30. Tensile test results of hybrid hemp and glass fiber composite specimens at 70°c temperature.

Table 19. Tensile test results for 4 layered hybrid hemp and glass fiber composite samples at 70°c temperature/

Fiber orientation	Sample	Thickness (mm)	Load at peak (kN)	Elongation at peak (mm)
$[0^0/0^0]$s	1	2.65	9.100	4.390
$[0^0/0^0]$s	2	2.61	7.850	4.350
$[0^0/0^0]$s	3	2.55	7.150	4.250
$[0^0/0^0]$s	4	2.57	6.900	3.650
$[0^0/0^0]$s	5	2.64	6.750	3.450
$[90^0/90^0]$s	1	2.60	6.500	3.400
$[90^0/90^0]$s	2	2.59	6.150	3.100

From the results, we observed that the peak load was higher when the fibers were aligned in the direction of the applied load, compared to when the fibers were perpendicular to the load.

Hybrid Linen and Glass Fiber Composites

The tensile test samples fabricated by using linen and glass fibers with six layers arranged symmetrically in a [0°/0°/0°]s and [90°/90°/90°]s orientations as shown in Figure 31. The samples were kept at 70°C temperature for 15 days. The results for along and across orientations of fiber samples are tabulated in Table 20 and the graphs are presented in Figure 32.

Figure 31. Hybrid linen and glass fiber composite specimens for tensile test at 70°c temperature.

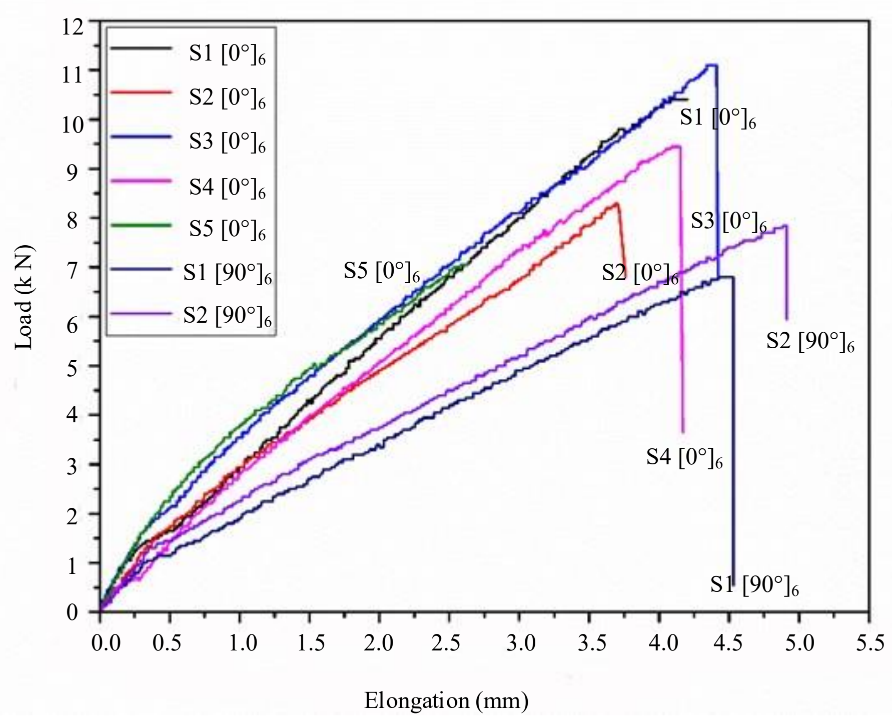

Figure 32. Tensile test results of hybrid linen and glass fiber composite specimens at 70°c temperature.

Table 20. Tensile test results for 6 layered hybrid linen and glass fiber composite samples at 70°c temperature.

Fiber orientation	Sample	Thickness (mm)	Load at peak (kN)	Elongation at peak (mm)
$[0^0/0^0/0^0]s$	1	3.90	11.100	4.750
$[0^0/0^0/0^0]s$	2	4.10	10.050	4.500
$[0^0/0^0/0^0]s$	3	3.85	9.450	4.300
$[0^0/0^0/0^0]s$	4	3.92	7.900	4.160
$[0^0/0^0/0^0]s$	5	4.10	7.550	4.050
$[90^0/90^0/90^0]s$	1	3.89	7.100	3.650
$[90^0/90^0/90^0]s$	2	3.96	6.150	2.750

Figure 33. Hemp fiber composite specimens for impact test at 70°c temperature.

From the results, we observed that the peak load was higher when the fibers were aligned in the direction of the applied load, compared to when the fibers were perpendicular to the load.

Impact Testing at 70°C Temperature

Hemp fiber composites

Impact test samples made from hemp fibers, arranged in four cross ply oriented layers [0°/90°]s, were tested using a drop weight setup as shown in Figure 33. The samples were kept at 70°C temperature for 15 days. In this test, a weight was dropped from different heights onto the samples, and the results are shown in Table 21.

As the drop height increased, the samples absorbed more energy. This shows a direct link between the height of the drop and the material's ability to absorb impact.

Linen Fiber Composites

Impact test samples made from hemp fibers, arranged in six cross ply oriented layers [0°/90°/0°]s, were tested using a drop weight setup as shown in Figure 34. The samples were kept at 70°C temperature for 15 days. In this test, a weight was dropped from different heights onto the samples, and the results are shown in Table 22.

Table 21. Impact test results for 4 layered hemp fiber composite samples at 70°c temperature.

Sample	Height (m)	Impact energy (J)	Energy absorbed (J)	Velocity (m/s)
1	0.05	3.301	1.865	0.990
2	0.08	5.281	2.995	1.252
3	0.10	6.602	3.610	1.400
4	0.12	7.922	4.019	1.534
5	0.14	9.242	4.062	1.657

Figure 34. Linen fiber composite specimens for impact test at 70°c temperature.

Table 22. Impact test results for 6 layered hemp fiber composite samples at 70°c temperature.

Sample	Height (m)	Impact energy (J)	Energy absorbed (J)	Velocity (m/s)
1	0.05	3.301	1.102	0.990
2	0.08	5.281	1.734	1.252
3	0.10	6.602	2.025	1.400
4	0.12	7.922	2.756	1.534
5	0.14	9.242	3.105	1.657

As the drop height increased, the samples absorbed more energy. This shows a direct link between the height of the drop and the material's ability to absorb impact. In simple terms, the higher the drop, the better the material was at taking the hit.

Hybrid Hemp and Glass Fiber Composites

Impact test samples made from hemp and glass fibers, arranged in four cross ply oriented layers [0°/90°]s, were tested using a drop weight setup as shown in Figure 35. The samples were kept at 70°C temperature for 15 days. In this test, a weight was dropped from different heights onto the samples, and the results are shown in Table 23.

The results shows a direct link between the height of the drop and the material's ability to absorb impact. In simple terms, the higher the drop, the better the material was at taking the hit.

Hybrid Linen and Glass Fiber Composites

Impact test samples made from linen and glass fibers, arranged in six cross ply oriented layers [0°/90°/0°]s, were tested using a drop weight setup as shown in Figure 36. The samples were kept at 70°C temperature for 15 days. In this test, a weight was dropped from different heights onto the samples, and the results are shown in Table 24.

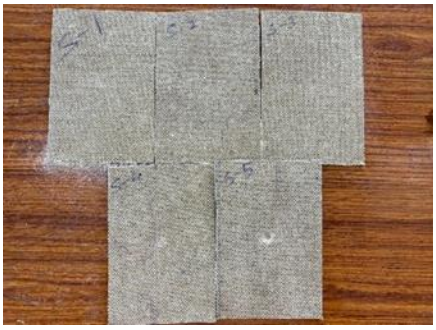

Figure 35. Hybrid hemp and glass fiber composite specimens for impact test at 70°c temperature.

Table 23. Impact test results for 4 layered hybrid hemp and glass fiber composite samples at 70°c temperature.

Sample	Height (m)	Impact energy (J)	Energy absorbed (J)	Velocity (m/s)
1	0.05	3.301	1.424	0.990
2	0.08	5.281	1.671	1.252
3	0.10	6.602	2.556	1.400
4	0.12	7.922	3.373	1.534
5	0.14	9.242	3.442	1.657

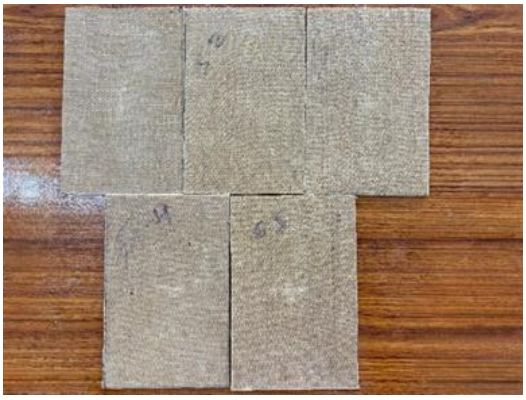

Figure 36. Hybrid linen and glass fiber composite specimens for impact test at 70°c temperature.

Table 24. Impact test results for 6 layered hybrid linen and glass fiber composite samples at 70°c temperature.

Sample	Height (m)	Impact energy (J)	Energy absorbed (J)	Velocity (m/s)
1	0.05	3.301	1.212	0.990
2	0.08	5.281	1.866	1.252
3	0.10	6.602	2.355	1.400
4	0.12	7.922	2.676	1.534
5	0.14	9.242	3.419	1.657

As the drop height increased, the samples absorbed more energy. This shows a direct link between the height of the drop and the material's ability to absorb impact.

CONCLUSIONS

The results clearly show that fiber orientation significantly affects material strength; specimens with fibers aligned along the load direction exhibit higher peak load capacity compared to those with fibers placed across the load. This alignment enhances strength performance and should be prioritized in composite design. Temperature also plays a crucial role in fiber effectiveness. Both hemp and linen fibers demonstrate their best performance at room temperature, with strength dropping as temperature increases. Hemp fiber is up to 9% more effective at room temperature compared to performance at 70°C, while linen fiber shows a similar trend with an 8% drop at higher temperatures.

Hemp and glass hybrid fiber composites perform better at room temperature than at 70°C, where it shows up to 7% less strength than at room temperature, depending on the sample.

Additionally, increasing drop height during impact tests reveals that the specimens can absorb more energy. This is due to internal mechanisms such as micro-cracking, which help dissipate the force and delay failure. Overall, fiber type, orientation, and operating temperature are key factors in optimizing the mechanical and impact performance of natural fiber composites.

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