

INVESTIGATION OF MECHANICAL AND WEAR PROPERTIES OF ALUMINIUM TRI HYDRATE FILLED JUTE AND FLAX FIBER REINFORCEMENT POLYMER COMPOSITE

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Abstract - Natural fiber composites offer a sustainable alternative to synthetic materials, but their mechanical performance is often limited, this research focuses on the fabrication and testing of composite materials using natural fibers, specifically jute and flax, with a polyester resin matrix. The study investigates the effect of adding Aluminum Tri hydrate (ATH) as a fire-retardant filler at varying concentrations of 10%, 20%, and 30% by weight. A hand lay-up technique followed by compression molding is employed for the fabrication of the composite laminates. The composite specimens are prepared in both varying concentrations of ATH 10%, 20%, 30% and without ATH of flax/jute fiber by Hand layup technique. The specimens are prepared according to ASTM standards. Mechanical tests such as tensile, flexural, impact, wear and Vickers hardness are conducted to determine ultimate tensile strength, bending strength, impact strength, hardness and wear of composites. The results demonstrate that optimal concentrations of 10%, 20%, 30% and without ATH by weight of flax/jute fiber parameters significantly improve the mechanical properties of the composites.

Key Words: flax and jute fibres, Nano powder (aluminium trihydrate)

1. INTRODUCTION

The first use of composites dates back to the 1500s B.C, when early Egyptians and Mesopotamian settlers used a mixture of mud and straw to create strong and sturdy buildings. The straw continued to reinforce ancient composite products, including pottery and boats. Later, in 200 ADS, the Mongols invented the primary composite bow employing a combination of wood bone and "animal

glue", bows were pressed and wrapped with birch bark. These bows are extremely powerful and highly accurate.

In the mid-20th century, global polymer production on this scale, which is present today, began with low material and production costs, new production technologies, and new product categories combined to make polymer production economical. The industry finally matured in the late 1970s when world polymer production surpassed that of steel, making polymers the ever-present material today. Fiber-reinforced plastics are a significant aspect of this industry. There are three important categories of fibers utilized in FRP: glass, carbon, and aramid. Glass fiber reinforcement is tested in military applications at the top of war 2, carbon fiber production began within the late 1950s and was used, though not widely in British industry beginning in the early 1960s, aramid fibers were produced around this time also, appearing 1st under the trade name Nomex by DuPont.

2. LITERATURE REVIEW

This chapter presents the work published in the literature on the natural fiber-reinforced polymer composites.

This is project primarily due to their environmentally friendly characteristics, including renewability, low cost, and biodegradability.

S.J. Skosana, C. Khoathane, T. Malwela, driving towards sustainability: A review of natural fiber reinforced polymer composites for eco-friendly automotive light- weighting, the automotive industry stands at a critical juncture, compelled by the imperative of sustainability to seek innovative materials for eco-friendly light-weighting. Natural fiber reinforced polymer composites (NFRPCs) have gained popularity due to their environmentally friendly nature and excellent engineering

capabilities J. Thermoplast. Compos Mater. 38 (2) (Feb. 2025) 754–780, <https://doi.org/10.1177/08927057241254324>.

.N. Sharath, Y.G. T.G, M. Puttegowda, Prospects of synthetic fiber-reinforced polymer composites in engineering and commercial applications. Proceeding of Applications of Composite Materials in Engineering, Within the domain of contemporary engineering and production, the pursuit of materials that exhibit exceptional performance, increased durability, and adaptability has resulted in the progression of composite materials. Synthetic Fiber Reinforced Polymer Composites (SFRPCs) have recently gained considerable attention as a promising category of materials that hold significant promise to bring about transformative advancements in a wide range of technical and commercial domains. Elsevier, 2025, pp.365–395, <https://doi.org/10.1016/B978-0-443-13989-5.00015-2>.

M.I.A. El Aal, M.M. Awd Allah, M.A. Abd El-baky, Carbon-glass reinforced epoxy hybrid composites for crashworthy structural applications, The goal of this work is to experimentally explore the crashworthiness performance and the deformation history of hybrid thin-walled composite tubes. Glass (G)/carbon (C) reinforced epoxy circular specimens were prepared by wet wrap using hand lay-up technique and then subjected to quasi-static axial compressive loads to examine the impact of the hybridization process and stacking sequences on the crashworthiness performance and the deformation history. Polym. Compos. 44 (5) (2023) 2910–2924, <https://doi.org/10.1002/pc.27290>

B.K. Sharma, et al., Advancements in bio-resource-based polymers and composites: sustainable alternatives to non-biodegradable plastics for a greener future: a review There is an urgent need to investigate viable alternatives to address the significant environmental concerns created by the widespread use of non-biodegradable and non-recyclable synthetic plastics. Bioresource-based polymers from natural materials such as starch, cellulose, chitosan, lignin, and agricultural waste have shown great promise., Curr. Green. Chem. 12 (2025), <https://doi.org/10.2174/10122133461372269250503082219>.

S. Siengchin, A review on lightweight materials for defence applications: present and future developments, The defence sector is now at an advanced level, catering to the global scenario, and countries also invest heavily in research and development. Countries around the world have spent a lot of money on research and development over the years in order to stay ahead of their competitors. Lightweight materials are critical in defence applications because they allow components to be lighter without sacrificing strength. This review provides an overview of the research related to defence applications. Def. Technol. 24 (2023) 1–17, <https://doi.org/10.1016/j.dt.2023.02.025..>

I.O. Oladele, L.N. Onuh, S. Siengchin, M.R. Sanjay, S.O. Adelani, Modern applications of polymer composites in structural industries: a review of philosophies, product development, and graphical applications, Polymer-based materials have been discovered as the most outstanding class of material that is fast displacing other materials in all areas of human needs. The dire need for durable, aesthetic, and lightweight materials has favored the increasing demand for polymer-based materials in structural industries. The application of polymeric-based materials in all aspects of human endeavor is based on their ease of formation, lightweight, and acceptable properties. Appl. Sci. Eng. Prog. (2023), <https://doi.org/10.14416/j.asep.2023.07.003>.

Md.Z.A. Mahmud, S.M.F. Rabbi, Md.D. Islam, N. Hossain, Synthesis and applications of natural fiber-reinforced epoxy composites: a comprehensive review, this review aims to provide a detailed analysis of the synthesis methods, properties, and applications of natural fiber-reinforced epoxy composites, highlighting their potential as sustainable materials for various industries. The objective of the study is to examine how different natural fibers such as jute, flax, hemp, and sisal impact the mechanical performance of epoxy composites. SPE Polym. 6 (1) (2025) e10161, <https://doi.org/10.1002/pls2.10161>

P. Jagadeesh, M. Puttegowda, P. Boonyasopon, S.M. Rangappa, A. Khan, S. Siengchin, Recent developments and challenges in natural fiber composites the

continuous demands for reducing environmental impact and energy consumption are the major driving factors for the development of natural fiber (NF)-reinforced composites (NFRCS). The huge demand for sustainable materials in industries leads to the usage of NFs in product developments. These NFs are more attractive due to their lightweight, cost-effectiveness, ease of availability, and environmentally friendly aspects: a review, **Polym. Compos** 43 (5) (2022) 2545–2561, <https://doi.org/10.1002/pc.26>

S. Palanisamy, K. Vijayananth, T.M. Murugesan, M. Palaniappan, C. Santulli, the prospects of natural fiber composite This research explores natural fiber composites (NFCs) as alternatives to traditional materials such as fiberglass. By examining fibers like abaca, bamboo, banana, coir, flax, hemp, jute, kenaf, pineapple leaf (PALF), sisal, and others, we emphasize their lower weight, cost-effectiveness, competitive mechanical properties, commendable specific strength, and potential for biodegradability. NFCs offer practical and eco-friendly substitutes for conventional composite fibers in industries like construction, automotive, and packaging. The article provides a brief overview of NFCs, covering their chemical, physical, and mechanical characteristics, and highlights diverse applications. The comparative analysis underscores the potential of natural fibers as sustainable choices in various industries.: a brief review, **Int. J. Lightweight Mater. Manuf.** 7 (4) (2024) 496–506, <https://doi.org/10.1016/j.ijlmm.2024.01.003>.

D. Bichang'a, F. Aramide, I. Oladele, O. Alabi, A review on the parameters affecting the mechanical, physical, and thermal properties of natural/synthetic fibre hybrid reinforced polymer composites, the global drive towards a circular economy that emphasizes sustainability in production processes has increased the use of agro-based raw materials like natural fibres in applications that have long been dependent on inorganic raw materials. Natural fibres provide an eco-friendly, more sustainable, and low-cost alternative to synthetic fibres that have been used for a long time in the development of composite materials. However, natural fibres are associated with high water absorption capacity due to their

hydrophilic nature leading to poor compatibility with hydrophobic polymeric matrices, thus lower mechanical properties for various applications. **Adv. Mater. Sci. Eng.** 2022 (2022) 1–28, <https://doi.org/10.1155/>

S. M. Sapuan et al. (2013) focused on the design and fabrication of natural fiber composites. Their research showed that proper selection of matrix, fiber, and filler combination is essential for achieving desired mechanical properties. They also observed that fillers like ATH improve stiffness and hardness while reducing production cost.

R. Mishra et al. (2003) investigated hybrid composites using jute and other natural fibers. Their study showed that combining different fibers improves overall performance due to better stress distribution. The authors also suggested that fillers can further enhance mechanical properties by strengthening the matrix phase.

PROBLEM IDENTIFICATION

A lot of literature is available on the investigation of mechanical properties of fibers with different reinforced materials. Most of the studies are made on the comparison of properties with reinforcement material and without reinforcement material.

Moreover, some research efforts on the material of Aluminum trihydrate of flax/jute fiber composites.

3. METHODOLOGY

The Fig. 4.1 shows the flow chart for the methodology of fabrication of flax/jute fiber Reinforced Composites.

Fig .1 Methodology for the fabrication of fiber

Hand Layup Method: Hand lay-up refers to the manual method of laying or applying the reinforcement material into the mould. In the hand lay-up process, the reinforcing material (usually natural fibres) is placed in the mould and then saturated with polyester resin using a brush and roller.

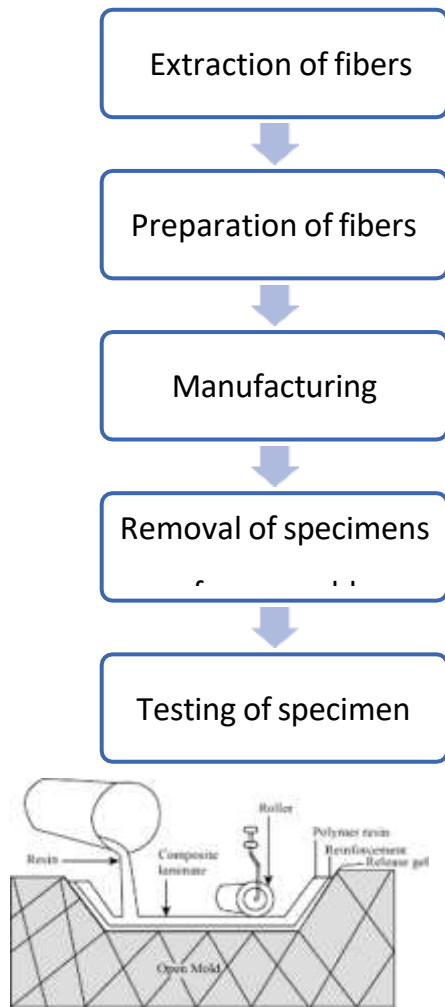


Fig.2 hand layup technique

3.1 Preparation of mould:

- Initially, sunglass sheets of 4 mm thick are cut according to the dimensions.
- The mould-made up of 4 mm thick is used for all testes.
- All the specimens are of cuboid shape.
- same volume percentage of fibers are used in the preparation of specimens by using these sunglass sheet mould.

Fig.3 mould

4.1 Preparation of flax and jute fibers mats:

- Take the flax and jute fiber mats .
- To cut fiber to required size and shape(30cmx30cm).
- To clean the mat perfectly for the specimen.
- After cleaning the fibers as

shown in Fig.4



Fig.4 flax and jute fibers

4.1 Preparation of Specimens without aluminum tri hydrate:

- After the cutting of flax and jute fiber mats, a mansion wax of 2 mm uniform thick is placed on flat sunglass sheet.
- Then the mould is placed on sunglass sheet.
- fibers of flax and jute are cut according to the length of the specimen and weighed using a precision balance.
- Then the required epoxy resin mixed with hardener is poured into the mould cavities in the ratio of 10:1.
- The composite contains a 60% volume of jute/coir fibers 40% of resin.
- Then the weighed fibers are placed layer by layer of one layer is flax fiber and other layer is jute fiber in the mould cavity in such a way that every layer gets mixed up with resin thoroughly.
- Then the weighed fibers are placed layer by layer of one layer is flax fiber and other



layer is jute fiber in the mould cavity in such a way that every layer gets mixed up with resin thoroughly.

- After placing the fiber again, a resin is poured.
- Top of the fiber is pressed tightly to avoid

air gaps between fiber composites.

- Weights are placed on it so that hardening gets easier.
- It is left for some time for hardening. Generally, it takes 24 hours is required for the hardening



Fig 5 preparation of specimen without ATH

4.2 Preparation of Specimens with 10% aluminum tri hydrate

- After the cutting of flax and jute fiber mats, a mansion wax of 2 mm uniform thick is placed on flat sunglass sheet.
- Then the mould is placed on sunglass sheet.
- fibers of flax and jute are cut according to the length of the specimen and weighed using a precision balance.
- Then the required epoxy resin mixed with hardener is poured into the mould cavities in the ratio of 10:1.
- The composite contains a 60% volume of jute/flax fibers 30% of resin resin in that 40% resin 10% ATH is added
- Then the weighed fibers are placed layer by layer of one layer is flax fiber and other layer is jute fiber in the mould cavity in such a way that every layer gets mixed up with resin thoroughly.
- After placing the fiber again, a resin is poured.
- Top of the fiber is pressed tightly to avoid air gaps between fiber composites.
- Weights are placed on it so that hardening gets easier.

- It is left for some time for hardening. Generally, it takes 24 hours is required for the hardening



Fig 6 preparation of specimen with 10 %ATH

4.3 Preparation of Specimens with 20% aluminum tri hydrate

- After the cutting of flax and jute fiber mats, a mansion wax of 2 mm uniform thick is placed on flat sunglass sheet.
- Then the mould is placed on sunglass sheet.
- fibers of flax and jute are cut according to the length of the specimen and weighed using a precision balance.
- Then the required epoxy resin mixed with hardener is poured into the mould cavities in the ratio of 10:1.
- The composite contains a 60% volume of jute/flax fibers 40% of resin in that 40% resin 20% ATH is added.
- Then the weighed fibers are placed layer by layer of one layer is flax fiber and other layer is jute fiber in the mould cavity in such a way that every layer gets mixed up with resin thoroughly.
- After placing the fiber again, a resin is poured.
- Top of the fiber is pressed tightly to avoid air gaps between fiber composites.
- Weights are placed on it so that hardening gets easier.
- It is left for some time for hardening. Generally, it takes 24 hours is required for the hardening



Fig 7 preparation of specimen with 20 %ATH



Fig 8 preparation of specimen with 30 %ATH

4.4 Preparation of Specimens with

30% aluminum tri hydrate

- After the cutting of flax and jute fiber mats, a mansion wax of 2 mm uniform thick is placed on flat sunglass sheet.
- Then the mould is placed on sunglass sheet.
- Fibres of flax and jute are cut according to the length of the specimen and weighed using a precision balance.
- Then the required epoxy resin mixed with hardener is poured into the mould cavities in the ratio of 10:1.
- The composite contains a 60% volume of jute/flax fibers 10% of resin in that 40% resin 30% ATH is added.
- Then the weighed fibers are placed layer by layer of one layer is flax fiber and other layer is jute fiber in the mould cavity in such a way that every layer gets mixed up with resin thoroughly.
- After placing the fiber again, a resin is poured.
- Top of the fiber is pressed tightly to avoid air gaps between fiber composites.



Removal of Specimens from the Mould:

- Weights are removed and specimens are to taken out from the mould carefully without any breakage as shown in Fig.4.9



Fig. 9 Removal of Specimen

- Mark each sample of fiber accordingly as shown in Fig.4.6



Fig.10 Marking of specimen

Now cut the specimens according to the marking using hand saw as shown in Fig.4.11

Fig.11 Cutting of specimen

- Weights are placed on it so that hardening gets easier.

4.7 After cutting of specimens

0% ATH specimens



Fig.12 Tensile test



fig.13 impact test

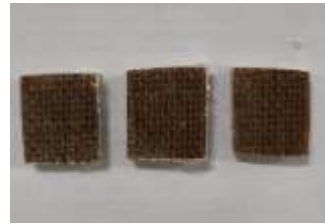


Fig.22 Hardness test



fig.23 wear test

Cutting test specimens of 20% ATH

30% ATH specimens



fig.24 Tensile test



fig.25 impact test



fig.26 wear test

Cutting test specimens of 0% ATH

10% ATH specimens



Fig.17 Tensile test



fig.18 impact test



fig.19 flexural test



fig.27 Flexural test



fig.28 hardness test

Cutting test specimens of 30% ATH



Fig.20 Hardness test



fig.21 wear test

Cutting test specimens of 10% ATH

20% ATH specimens



Tensile test



impact test



flexural test

TESTING OF COMPOSITES

Testing of composites is performed to determine the mechanical properties of the material.

5.1 Testing Equipment

The types of equipment used for testing of composites are Universal testing machine, Impact testing machine, Vickers hardness machine and wear testing machine description as follows



Fig.29 Universal testing machine:

Universal testing machine, TSI BSD 10KN model shown in Fig. 5.1 is used to find the Tensile/ Compression / Flexural tests on different Non-Ferrous/Polymer/Rubber materials conforming to ASTM standards. Application Software used was Windows based user-friendly software with easy user interface. The test speed was 1 mm/min to 500 mm/min.

Universal testing machine

5.1.1 IZOD IMPACT TESTING MACHINE:

Izod impact testing machine, AE-ICIT-AI-TS model shown in Fig. 30 is used to find the Izod and Charpy impact test on different materials conforming to ASTM standards. Impact speed was 3.46 m/s.



Fig .30 Izod impact testing machine
Notch Cutter

Notch cutter, AE-MNC-D model as shown in Fig 5.3 is used to create a notch on impact test specimens. The travel range is 0 – 9.999 mm. Accuracy is +/- 0.002 mm and the cutting speed is 150 mm/min.

Fig.31 Notch cutter



Vickers hardness testing machine

Vickers hardness was measured using a Vickers tester with 0.05 kg load and 15-second dwell time as shown in Fig 5.4. The automated system's 40x lens and precision XY stage (0.1μm resolution) enabled accurate indentation imaging. Hardness values (HV) were calculated from diagonal measurements to assess surface durability.

These spacing ensured independent measurements and provided a representative assessment of the material's hardness distribution. The instrument's automated hardness calculation feature eliminated potential operator bias by directly converting the optical measurements of indentation diagonals into Vickers hardness numbers (HV) with high traceable accuracy.



Fig.32 Hardness testing machine

WEAR TESTING MACHINE

A wear test utilizing a pin-on-disk apparatus is a foundational and widely adopted method in tribology for studying the friction and wear behavior of materials under controlled sliding conditions. At its core, the setup consists of two primary components: a stationary pin and a rotating disk.

The pin, which can be cylindrical, spherical, or another specific geometry, is the material under investigation for its wear resistance. It is held in a fixture and pressed against the surface of a flat, circular disk by applying a precisely controlled normal load. This load can be achieved through dead weights,

pneumatic, or hydraulic systems, ensuring a consistent force pushing the pin against the disk throughout the test.



Fig. pin-on-disk wear test machine

Specimen Standards

Tensile Test

The specimens for the tensile test were prepared according to the ASTM D-3039-76 Standard. According to this standard, the specimen size is 153mm x12.7mm x4mm. The specimens were tested on a tensile testing machine. From the experimental data, the stress-strain curve is plotted to determine the young's modulus and tensile



strength.



Tensile tested specimen of 0% ATH

Tensile tested specimen of 10% ATH



Tensile tested specimen Of 20% ATH



Tensile tested specimen of 30% ATH

5.1.1 Flexural Test

The specimens for the flexural test were prepared according to the ASTM D-785 Standard. The dimensions of the specimen as per this standard are 100mm x12.7mm x4mm. The flexural test performed on the same Universal testing machine that was used to perform the tensile test. Load and deformation values are noted and flexural modulus and flexural strength are determined. Specimens were prepared for each volume fraction of fibers. The specimens after the flexural test are shown in Fig 5.11, Fig 5.12, Fig5.13&Fig5.14



Fig.5.11 Flexural tested specimen with 0% ATH

Fig.5.12 Flexural test specimen with 10% ATH



Fig.5.13 Flexural tested specimen with 20% ATH



Fig.5.14 Flexural test specimen with 30% ATH

5.1.1 Impact Test:

The impact test specimens were prepared according to the ASTM D-256 Standard. The dimensions of the specimens as per this standard are 63.5mmx12.7mmx 10mm. Impact test (IZOD) was conducted on the specimen and the impact strength is determined. The energy absorbed in the impact test will be a measure of toughness. Specimens were prepared for each volume fraction.



Fig.5.15 impact tested specimen with 0% ATH Fig.5.16 impact test specimen with 10% ATH



Fig.5.17 impact tested specimen with 0% ATH Fig.5.18 impact test specimen with 10% ATH

5.1.1 Vickers hardness Test:

Hardness values (HV) were calculated from diagonal measurements to assess surface durability. Testing covered multiple locations per sample for consistency. Each test series comprised 6 indentations per specimen, strategically spaced at a distance of at least three times the indentation diagonal length to prevent overlap and mechanical interaction between test sites. These spacing ensured independent measurements and provided a representative assessment of the material's hardness distribution. The specimens after the hardness test are shown in Fig. 5.19 Fig. 5.20, fig 21&fig.22



Fig.5.19 hardness tested specimen with 0% ATH Fig.5.20 hardness test specimen with 10% ATH



Fig.5.21 hardness tested specimen with 0% ATH Fig.5.22 hardness test specimen with 10% ATH

5.1.1 Wear Properties

A wear test utilizing a pin-on-disk apparatus is a foundational and widely adopted method in tribology for studying the friction and wear behavior of materials under controlled sliding conditions. At its core, the setup consists of two primary components: a stationary pin and a rotating disk.

Beyond friction and wear volume, advanced pin-on-disk tribometers can also monitor other parameters like vertical displacement (indicating wear depth in real-time) and temperature at the contact interface, as friction can generate heat. The test environment can also be controlled, allowing for experiments in specific temperatures, humidity levels, or even in the presence of lubricants or different gas atmospheres (e.g. Inert gas or vacuum).



Fig 5.23 – Wear test specimens

The pin-on-disk test (ASTM G99) provides valuable data on wear mechanisms, material performance, and lubricant effectiveness. It allows standardized comparison of wear resistance. However, due to its simplified geometry and controlled setup, it may not fully replicate real-world tribological conditions, making it an idealized but informative evaluation method.

RESULTS AND DISCUSSIONS

The composites are moulded with epoxy resin and reinforced without aluminum trihydrate of flax/jute fibers and flax/jute fibers with 10% of ATH and flax/jute fibers with 20% of ATH and flax/jute fibers with 30% of ATH. The fibers are arranged manually in the mould in the specimen. The variation in alignment in the mould is found to be small and neglected. The fibers are arranged in the mould to cover uniformly over its full length.

The effect of non-uniformity may be very small and expected to have a very small variation in the test results. For each test, three identical specimens of the same fiber are prepared and their dimensions are measured. The variation of the dimensions of the specimen is very small

when compared to the standard dimensions. However, the properties are calculated based on the measurement of actual dimensions of individual specimens. Finally, the average properties of the three specimens are considered for calculating the percentage volume of the fiber present in the specimen.

TENSILE TEST:

Universal testing machine is used for conducting a tensile test on flax/jute fiber reinforced composites 0%, 10%, 20% and 30% aluminum trihydrate. The result of tensile test such as ultimate tensile strength, percentage of elongation. Are shown in Table 6.1

Table 6.1 Results of tensile test

Composite reinforcement with flax/jute fibers	Specimen (153mm x 12.7mm x 4mm)	Ultimate Tensile Strength(N/mm ²)	Average ultimate tensile strength (N/mm ²)	Percentage of Elongation (%)
0% ATH of fiber reinforcement composite	Sample-1	36.58	30.6933	14.24
	Sample-2	25.15		38.72
	Sample-3	30.35		18.21
10% ATH of fiber reinforcement composite	Sample-1	38.34	33.83	7.64
	Sample-2	29.78		7.52
	Sample-3	33.38		9.20
20% ATH of fiber reinforcement composite	Sample-1	40.51	34.099	7.96
	Sample-2	31.33		12.72
	Sample-3	30.45		10.84
30% ATH of fiber reinforcement composite	Sample-1	38.21	32.16	8.88
	Sample-2	28.29		11.04
	Sample-3	29.98		12.24

The table 6.1 presents the results of a tensile test conducted on composite materials reinforced with flax/jute fibers, comparing 0% ATH fibers with those 10% ATH 20% ATH and 30% ATH. Each category includes three samples, and their ultimate tensile strength (UTS) and percentage of elongation were measured

showed a slightly improved average UTS of 33.83N/mm², with individual values ranging from 33.38 to 38.34 N/mm². The elongation percentages for treated samples ranged from 7.52% to 7.64%, the 20% is maximum point of average is 34.099 and the elongation is varies of 12.72 to 7.96. And the 30% ATH composition is slightly decreased the average tensile strength is 32.16 and elongation varies from 11.04 to 8.88. Slightly enhances the tensile strength of the composite, likely due to better bonding between the fiber and matrix maximum at 20% ATH and minimum at 0% ATH.

IMPACT TEST:

Impact testing machine is used for conducting a Izod test on flax/jute fiber reinforced composites 0%, 10%, 20% and 30% aluminum trihydrate. The result of Impact test such as impact strength is shown in Table 6.2

Table 6.2 Results of Impact test

Composite reinforcement with coir/jute fibers	Specimen (64mm x 12.7mm x 4mm)	Impact strength(J)	Average Impact strength(J)
0% ATH of fiber reinforcement composite	Sample-1	2.322	2.148
	Sample-2	2.412	
	Sample-3	1.710	
10% ATH of fiber reinforcement composite	Sample-1	2.232	2.322
	Sample-2	2.322	
	Sample-3	2.412	
20% ATH of fiber reinforcement composite	Sample-1	2.782	2.758
	Sample-2	3.262	
	Sample-3	2.232	
30% ATH of fiber reinforcement composite	Sample-1	3.164	3.368
	Sample-2	2.877	
	Sample-3	4.065	

The table 6.2 presents the results of an impact test conducted on composite materials reinforced with flax/jute fibers, comparing 0% ATH fibers with those 10% ATH 20% ATH and 30% ATH. Each group includes three samples, and their impact strength values were recorded.

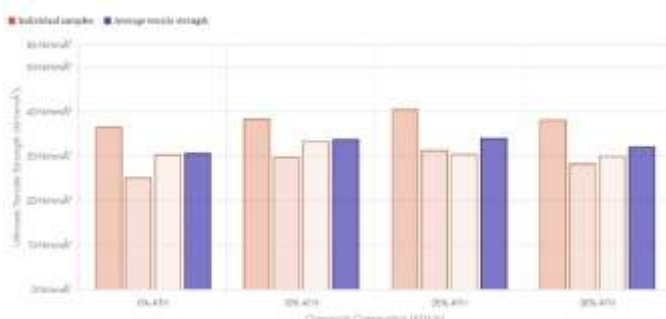


Fig. 6.1 Results of tensile test

For the 0% ATH of fiber composite, the UTS values ranged from 36.58 to 30.35N/mm², with an average tensile strength of 30.6933N/mm² and elongation percentages between 14.14% and 38.72%. In comparison, the 10% ATH fiber composite

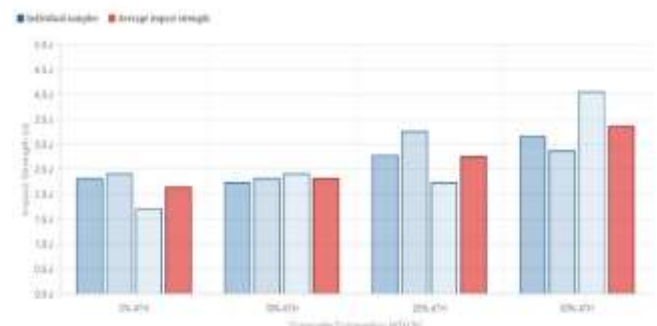


Fig. 6.2 Results of Impact test

For the 0% ATH with fiber reinforcement composite, the impact strengths ranged from 1.710 J to 2.412J, resulting in an average impact strength of 2.148J. In contrast, the 10% ATH with fiber composite showed impact strengths ranging from 2.232 J to 2.412 J, with a

significantly higher average of 2.322J. And the 20% ATH with fiber composite shows the impact strength is varies from 2.322 to 2.782 J and the average is 2.758. And maximum at the 30% ATH varies from 2.877 to 4.065 and the average is 3.368. This increase indicates that the Aluminum Trihydrate is improves the energy absorption capability of the composite material. Specifically, Sample-3 in 30% ATH in the group achieved a notably high impact strength of 4.065 J, which suggests enhanced bonding between the fiber and matrix due to the ATH as shown in Fig.6.2. Overall, the results demonstrate that Aluminum trihydrate of natural fibers can effectively increase the impact resistance of the composite material, likely due to improved interfacial adhesion and fiber surface roughness.

FLEXURAL TEST:

Universal testing machine is used for conducting a flexural test on flax/jute fiber reinforced composites 0%, 10%, 20% and 30% aluminum trihydrate. The result of Flexural test such as flexural strength is shown in Table 6.3

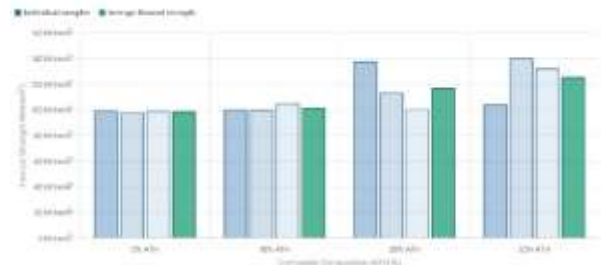
Table 6.3 Results of flexural test

Composite reinforcement with coir/jute fibers	Specimen (100mm x 12.7mm x 4mm)	Flexural strength(N/mm ²)	Average Flexural strength(N/mm ²)
0% ATH of fiber reinforcement composite	Sample-1	99.3	98.80
	Sample-2	97.98	
	Sample-3	99.13	
10% ATH of fiber reinforcement composite	Sample-1	100.12	101.73
	Sample-2	99.98	
	Sample-3	105.13	
20% ATH of fiber reinforcement composite	Sample-1	137.7	117.16
	Sample-2	113.3	
	Sample-3	100.5	
30% ATH of fiber reinforcement composite	Sample-1	104.3	125.54
	Sample-2	140.18	
	Sample-3	132.16	

The table 6.3 shows the results of a flexural test conducted on composite materials reinforced with flax/jute fibers, comparing 0% ATH fibers with those 10% ATH 20% ATH and 30% ATH.

Three specimens from each group were tested, and their flexural strength (in N/mm²) was measured to evaluate the material's ability to resist deformation under bending.

Fig.6.3 Results of flexural test



For the 0% ATH fiber composite, the flexural strength values ranged from 97.98 to 99.3N/mm², with an average value of 98.80 N/mm². For the 10% ATH fiber composite, the flexural strength values ranged from 100.12 to 105.13N/mm², with an average value of 101.73N/mm². For the 20% ATH fiber composite, the flexural strength values ranged from 113.3to 137.7N/mm², with an average value of 117.16 N/mm². For the 30% ATH fiber composite, the flexural strength values ranged from 132.16 to 140.18N/mm², with an average value of 125.54N/mm²In comparison, the ATH is increased in fiber composite showed improved flexural strength

Overall, the results indicate that aluminum trihydrate has a positive effect on the flexural performance of the composite material, contributing to greater structural integrity and stiffness.

HARDNESS TEST:

Hardness testing machine is used for conducting a tensile test on coir/jute fiber reinforced composites both treated and untreated forms. The result of Hardness test such as Vickers Hardness is shown in Table 6.4

Table 6.4 Results of hardness test

Composite reinforcement with coir/jute fibers	Specimens	Vickers Hardness (HV)	Average Vickers Hardness
0% ATH of fiber reinforcement composite	Sample-1	48.58	49.53
	Sample-2	50.40	
	Sample-3	49.62	
10% ATH of fiber reinforcement composite	Sample-1	56.98	57.67
	Sample-2	58.31	
	Sample-3	57.74	
20% ATH of fiber reinforcement composite	Sample-1	65.67	68.70
	Sample-2	67.63	
	Sample-3	66.73	
30% ATH of fiber reinforcement composite	Sample-1	72.81	73.76
	Sample-2	74.75	
	Sample-3	73.72	

The table 6.4 shows the results of a hardness test performed on composite materials reinforced with flax/jute fibers, comparing 0% ATH fibers with those 10% ATH 20% ATH and 30% ATH. Each group consists of three specimens, and the Vickers hardness of each was measured to evaluate surface resistance to indentation.

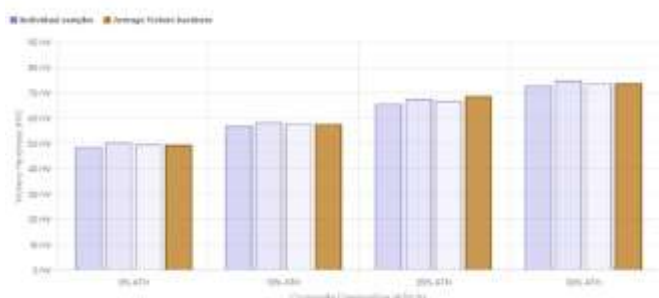


Fig. 6.4 Results of hardness test

For the 0% ATH with fiber composite, the Vickers hardness values ranged from 48.58 to 50.40, with an average hardness of 49.53. And 10% ATH with fiber composite, the Vickers hardness values ranged from 56.98 to 58.31, with an average hardness of 57.67. And 20% ATH with fiber composite, the Vickers hardness values ranged from 65.67 to 67.63, with an average hardness of 68.70. And 30% ATH with fiber composite, the Vickers hardness values ranged from 72.81 to 74.75 with an average hardness of 73.76. In contrast, the 30% ATH with fiber composite exhibited significantly higher hardness values, ranging from 72.81 to 74.75, resulting in an average Vickers hardness of 73.76.

This noticeable increase in hardness after adding ATH suggests improved mechanical integrity and better interfacial bonding between the fibers and matrix. The ATH is enhanced the fiber surface roughness, enabling more effective stress transfer during indentation as shown in Fig.6.4. Overall, the

results indicate that aluminum trihydrate enhances the hardness of the composite, making it more resistant to surface deformation and wear.

WEAR TEST

The Taguchi L16 orthogonal array was employed to design experiments with four factors at four levels, significantly reducing the number of experimental trials while ensuring reliable optimization of wear performance

Table 6.5 – Variables table

% of ATH	Load (KG)	Sliding Distance (m)	Velocity (m/s)
0	0.5	500	0.5
10	1	1000	1
20	1.5	1500	1.5
30	2	2000	2

Table 6.6 – L16 array table

Exp No	% of ATH	Velocity (m/s)	Load(kg)	Sliding Distance(km)
1	0	0.5	0.5	0.5
2	0	1	1	1
3	0	1.5	1.5	1.5
4	0	2	2	2
5	10	0.5	1	1.5
6	10	1	0.5	2
7	10	1.5	2	0.5
8	10	2	1.5	1
9	20	0.5	1.5	2
10	20	1	2	1.5
11	20	1.5	0.5	1
12	20	2	1	0.5
13	30	0.5	2	1
14	30	1	1.5	0.5
15	30	1.5	1	2
16	30	2	0.5	1.5

The Taguchi method is a statistical approach used to optimize process parameters and improve product quality with a minimum number of experiments. The L16 orthogonal array is one of the most commonly used

designs in this method, especially when three factors are studied at three different levels. Instead of performing all possible combinations the L16 array reduces the number of experiments to just 16 while still providing reliable and systematic results. In this design, each factor is varied independently, and the arrangement ensures balanced comparison of levels, allowing the effect of each parameter to be evaluated efficiently.

4.6.1 Table of Wear test results

Exp No	Factor 1	Factor 2	Factor 3	Factor 4	Wear rate	Coefficient of friction
1	1	1	1	1	40.48	1.88
2	1	2	2	2	50.28	2.82
3	1	3	3	3	118.53	4.18
4	1	4	4	4	96.94	4.43
5	2	2	3	3	148.75	6.18
6	2	1	4	4	120.88	6.51
7	2	4	1	1	50.44	5.33
8	2	3	2	2	68.36	6.31
9	3	3	4	4	308.66	7.12
10	3	4	3	3	418.2	9.28
11	3	1	2	2	63.77	10.36
12	3	2	1	1	128.92	10.77
13	4	4	2	2	143	11.12
14	4	3	1	1	126.5	13.13
15	4	2	4	4	53.36	13.18
16	4	1	3	3	160.18	14.28

Taguchi Analysis: wear for flax and jute fiber with Aluminum Trihydrate

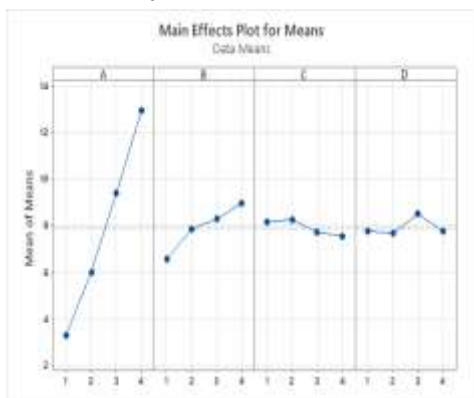
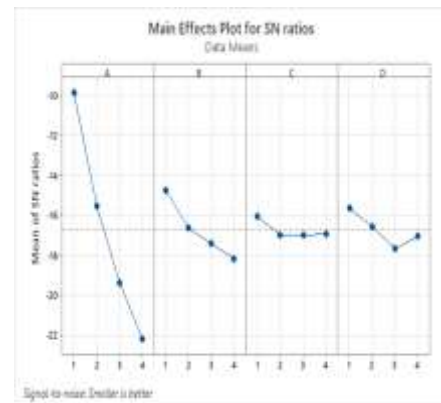


Fig 6.5 -Means graph for wear

Fig 6.6-SN ratios graph for wear



The main effects plot for means and signal-to-noise (S/N) ratios clearly illustrate the influence of process parameters such as ATH content (A), applied load (B), sliding speed (C), and sliding distance (D) on the coefficient of friction of the glass fiber reinforced epoxy composite.

From the main effects plot for means, it is observed that the coefficient of friction increases with increasing levels of applied load (B) due to higher normal force and increased interfacial interaction between the contacting surfaces. Similarly, sliding speed (C) and sliding distance (D) show a moderate increasing trend, attributed to frictional heating and surface degradation during prolonged sliding.

In contrast, ATH content (A) shows a decreasing trend in friction coefficient with increasing levels. This indicates that the addition of aluminum trihydrate improves surface smoothness and hardness, thereby reducing resistance to sliding. The reduction in friction is more significant at higher ATH levels (20–30%), where the filler forms a protective layer at the contact interface.

From the main effects plot for S/N ratios (smaller-is-better), the increasing S/N values with higher ATH content confirm the improvement in frictional performance. Among all parameters, load (B) exhibits the most significant variation, indicating that it is the dominant factor influencing friction. Sliding speed (C) and distance (D) show secondary effects, while ATH content (A) consistently contributes to lowering friction and improving stability.

Taguchi Analysis: friction for flax and jute fiber with Aluminum Trihydrate

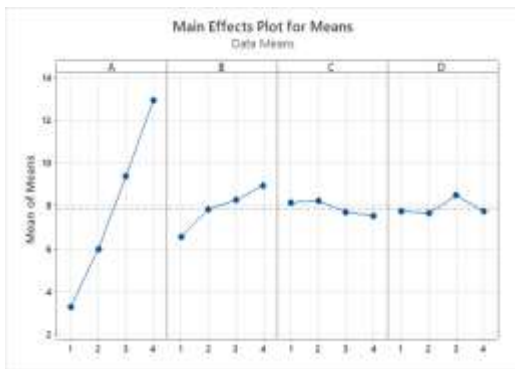


Fig 6.7 -Means graph for friction

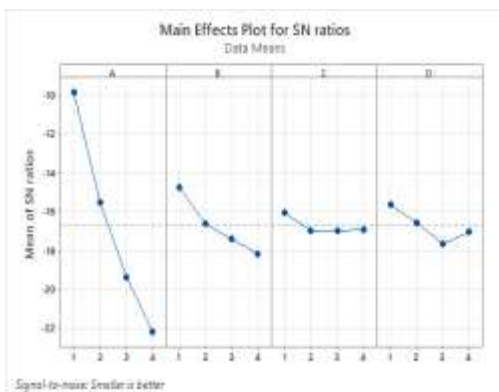


Fig 6.8 -SN ratios graph for friction

The main effects plots for means and signal-to-noise (S/N) ratios clearly illustrate the influence of process parameters such as ATH content (A), applied load (B), sliding speed (C), and sliding distance (D) on the coefficient of friction of the jute–flax fiber reinforced epoxy composite.

From the main effects plot for means, it is observed that the coefficient of friction increases with increasing levels of applied load (B) due to higher normal force and increased interfacial interaction between the contacting surfaces. Similarly, sliding speed (C) and sliding distance (D) show a moderate increasing trend, attributed to frictional heating and surface degradation during prolonged sliding.

In contrast, ATH content (A) shows a decreasing trend in friction coefficient with increasing levels. This indicates that the addition of aluminum trihydrate improves surface smoothness and hardness, thereby reducing resistance to sliding. The reduction in friction is more significant at higher ATH levels (20–30%), where the filler forms a protective layer at the contact interface.

From the main effects plot for S/N ratios (smaller-is-better), the increasing S/N values with higher ATH content confirm the improvement in frictional performance. Among all parameters, load (B) exhibits the most significant variation, indicating

that it is the dominant factor influencing friction. Sliding speed (C) and distance (D) show secondary effects, while ATH content (A) consistently contributes to lowering friction and improving stability.

CONCLUSION AND SCOPE FOR FUTURE WORK

CONCLUSION:

The composite was fabricated using a hybrid combination of flax and jute fibers. A series of mechanical tests tensile, impact, hardness, flexural and wear tests were conducted to evaluate the effect of Aluminum trihydrate on flax/jute fiber-reinforced composite materials. The performance of 0% ATH, 10% ATH, 20% ATH, 30% ATH in fiber composites was compared across all tests using three specimens per group. The results consistently indicate that ATH improves 10% and 20% composition and slightly decreased in 30% ATH composition of the mechanical properties of the composite material.

The present study on jute and flax fiber reinforced polymer composites filled with aluminum trihydrate (ATH) demonstrates that natural fiber hybridization combined with appropriate filler addition can significantly enhance composite performance.

1. In the tensile test, the average ultimate tensile strength increased from 30.6933 N/mm²(0%ATH) to 34.099 N/mm²(20%ATH), reflecting a modest but positive improvement. This suggests that aluminum trihydrate enhance up to 20% after that slightly decrease the interfacial bonding between the natural fibers and the matrix, allowing for better stress transfer under tensile loading.
2. The impact test revealed a more significant enhancement in performance, with the average impact strength increasing from 2.148 J (0% ATH) to 3.368 J (20% ATH). This indicates that aluminum trihydrate significantly improves the composite's ability to absorb energy and resist sudden impact loads. The increased toughness is attributed to improved fiber surface roughness and bonding after adding aluminum trihydrate.
3. In the hardness test, the Vickers hardness values showed a noticeable increase from an average of 49.53 (0%ATH) to 73.76 (30%ATH). This indicates better resistance to surface indentation and wear,

further confirming improved material integrity and interfacial adhesion resulting from aluminum trihydrate.

4. The flexural test also showed an increase in average flexural strength from 98.80 N/mm² (untreated) to 125.54 N/mm² (treated). While the improvement is relatively modest, it still reflects enhanced load-bearing capacity and stiffness under bending stresses due to the improved fiber-matrix interface.
5. The results show that wear loss and wear rate decrease consistently with increasing ATH content, with the 30% ATH composite exhibiting minimum wear due to its higher hardness and improved resistance to surface deformation. The presence of ATH particles enhances load-bearing capacity and forms a protective layer at the sliding interface, thereby reducing material removal.
6. Overall, the experimental data demonstrate that aluminum trihydrate significantly enhances the mechanical performance of flax/jute fiber-reinforced composites. The improvements are particularly prominent in impact strength and hardness, with consistent gains in flexural strength as well and improve tensile strength up to 20% after slightly decreased. These enhancements are primarily due to the removal of impurities and increased surface roughness of fibers, which lead to better mechanical interlocking and stronger adhesion with the matrix. Therefore, Aluminum trihydrate proves to be an effective nanoparticle for improving the structural properties of natural fiber composites, making them more suitable for engineering and industrial applications.

SCOPE FOR FUTURE WORK

- **Thermal Properties Study:** research can be extended to analyze the thermal properties (e.g., thermal conductivity, thermal stability) of flax/jute fiber-reinforced composites alongside mechanical properties.
- **Optimization of Alkali Treatment:** Investigate the effects of varying NaOH concentrations and soaking durations to determine optimal conditions for fiber treatment.
- **Microstructural Analysis:** Use Scanning Electron Microscopy (SEM) to examine the surface morphology and fiber-matrix bonding

in both treated and untreated composites.

- **Use of Fiber Powder:** Explore the mechanical performance of composites reinforced with flax or jute fiber powder instead of traditional fiber forms.
- **Hybrid Composite Development:** Develop hybrid composites by combining flax/jute fibers with other fibers or **nanoparticles** to enhance overall material properties.

REFERENCES

- [1] S.J. Skosana, C. Khoathane, T. Malwela, **Driving towards sustainability:** A review of natural fiber reinforced polymer composites for eco-friendly automotive lightweighting, J. Thermoplast. Compos. Mater. 38 (2) (Feb. 2025) 754–780, <https://doi.org/10.1177/08927>
- [2] B.N. Sharath, Y.G. T.G, M. Puttegowda, Prospects of synthetic fiber-reinforced polymer composites in engineering and commercial applications. Proceeding of Applications of Composite Materials in Engineering, Elsevier, 2025, pp. 365–395, <https://doi.org/10.1016/B978-0-443-13989-5.00015-2>
- [3] M.I.A. El Aal, M.M. Awd Allah, M.A. Abd El-baky, Carbon-glass reinforced epoxy hybrid composites for crashworthy structural applications, Polym. Compos. 44 (5) (2023) 2910–2924, <https://doi.org/10.1002/pc.27290>.
- [4] B.K. Sharma, et al., Advancements in bio-resource-based polymers and composites: sustainable alternatives to non-biodegradable plastics for a greener future: a review, Curr. Green. Chem. 12 (2025), <https://doi.org/10.2174/0122133461372269250503082219>.
- [5] S. Siengchin, A review on lightweight materials for defence applications: present and future developments, Def. Technol. 24 (2023) 1–17, <https://doi.org/10.1016/j.dt.2023>
- [6] I.O. Oladele, L.N. Onuh, S. Siengchin, M.R. Sanjay, S.O. Adelani, Modern applications of polymer composites in structural industries: a review of philosophies, product development, and graphical applications, Appl. Sci. Eng. Prog. (2023), <https://doi.org/10.14416/j.asep.2023.07.003>
- [7] Md.Z.A. Mahmud, S.M.F. Rabbi, Md.D. Islam, N. Hossain, Synthesis and applications of natural fiber-reinforced epoxy composites: a comprehensive review, SPE Polym. 6 (1) (2025) e10161, <https://doi.org/10.1002/pls2.10161>.
- [8] P. Jagadeesh, M. Puttegowda, P. Boonyasopon, S.M. Rangappa, A. Khan, S.

Siengchin, Recent developments and challenges in natural fiber composites: a review, Polym. Compos 43 (5) (2022) 2545–2561, <https://doi.org/10.1002/pc.2661>

[9] **S. Palanisamy, K. Vijayananth, T.M. Murugesan, M. Palaniappan, C. Santulli**, The prospects of natural fiber composites: a brief review, Int. J. Lightweight Mater. Manuf. 7 (4) (2024) 496–506, <https://doi.org/10.1016/j.ijlmm.2024.01.003>.

[10] **D. Bichang'a, F. Aramide, I. Oladele, O. Alabi**, A review on the parameters affecting the mechanical, physical, and thermal properties of natural/synthetic fibre hybrid reinforced polymer composites, Adv. Mater. Sci. Eng. 2022 (2022) 1–28, <https://doi.org/10.1155/2022/70>

[11] **A.A. Bachchan, P.P. Das, V. Chaudhary**, Effect of moisture absorption on the properties of natural fiber reinforced polymer composites: a review, Mater. Today Proc. 49 (2022) 3403–3408, <https://doi.org/10.1016/j.matpr.2021.02.812>.

[12] **R. Mishra et al. (2003)** investigated hybrid composites using jute and other natural fibers.

[13] **S.C. Das, et al.**, Effect of stacking sequence on the performance of hybrid natural synthetic fiber reinforced polymer composite laminates, Compos. Struct.

[14] **Y. Li, Y. Mai, and L. Ye (2000)** studied the effect of fiber surface treatment on the mechanical properties of natural fiber composites.

[15] **J. P. Davim et al. (2010)** analyzed the mechanical behavior and machinability of natural fiber composites.

[16] **M.K. Gupta, M. Ramesh, S. Thomas**, Effect of hybridization on properties of natural and synthetic fiber-reinforced polymer composites (2001-2020): a review, Polym. Compos, 42 (10) (2021) 4981-5010, <https://doi.org/10.1002/pc.26244>.

[17] **H.N. Abdelhamid**, Natural and synthetic fiber-reinforced polymer composites and their impact on aging under environmental conditions. Proceeding of Aging and Durability of FRP Composites and Nanocomposites, Elsevier, 2024, pp. 171-188,