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Fabrication and Characterisation of Chitosan–Palm Fiber Reinforced Polymer Composites

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ABSTRACT- *The concept of natural Fiber-reinforced polymer composites has been introduced to replace synthetic Fiber composites, as they are low-density, biodegradable, and environmentally friendly. This paper has produced palm Fiber-reinforced polyester composites with chitosan as a bio-filler in order to increase the effectiveness of Fiber-matrix bonding and to elevate thermomechanical performance. Three composite formulations were made by the hand lay-up method, keeping the content of palm Fibers at 60 per cent constant, and the chitosan filler content at 1-3 per cent and 5 per cent of the weight. The developed samples were tested in tensile, flexural tests, impact tests, hardness, thermal conductivity tests, water absorption tests, and flammability tests as per ASTM standards. The mechanical test results showed that the addition of 3% chitosan enhanced tensile strength (23.87 N/mm2) and flexural strength (51.30 N/mm2) significantly due to the enhancement of interfacial bonding and minimisation of the voids development. Nevertheless, increasing chitosan loading (5 per cent) led to some performance losses presumably because of agglomeration of fillers and discontinuities in the matrix. Thermal conductivity was less than 0.26 (0.21 W/m 3 K) with increasing filler content, which showed better thermal insulation properties. At the same time, the absorption of water was slightly higher when the contents of chitosan were higher, as both palm Fibers and biopolymeric fillers are hydrophilic. Every composite variant had a UL-94 V-1 flammability rating, which is a moderate flame resistance. On the whole, the results emphasise the fact that polyester composites reinforced with palm Fiber and filled with chitosan in the most ideal way demonstrate good mechanical, thermal, and functional characteristics that can be used in the lightweight structural, automotive, and interior sectors. More fine-tuning of the filler scattering would be advised to improve the stability of performance.*

Keywords: palm Fiber; Polyester resin; Chitosan filler; Natural Fiber composites; Mechanical properties; Thermal characterisation; Hand lay-up process; Sustainable materials.

1 INTRODUCTION

The growing worldwide interest in sustainable engineering materials has sped up the replacement of synthetic with natural Fiber-reinforced polymer composites (NFRPCs). Traditional synthetic Fibers like glass, carbon, and aramid are mechanically better but are associated with non-biodegradability, the high-energy usage during the manufacturing process, and the end-of-life products to the environment. By comparison, natural Fibers provide an attractive balance of biodegradability, low density, cost-efficiency and lower environmental impact, so they are viable options to substitute the synthetic reinforcement in many industrial uses. Palm Fiber has also received significant attention among other natural Fibers that have been investigated in the last decade, including jute, hemp, banana, and coir (Joseph et al., 2015).

The polymer composite reinforcement with palm Fiber is especially appealing due to its natural toughness, biodegradability, as well as compatibility with thermosetting matrices. Combined with polymeric binders, it competently mechanically interlocks owing to its cellular structure and surface morphology, but, similar to most lignocellulosic Fibers, is hydrophilic and exhibits weak interfacial binding with hydrophobic polymer matrix. Hence, scientists have also paid attention to studying the modifiers and fillers that can improve the bonding at the Fiber-matrix interface. Chitosan is a biopolymer derived naturally as a result of chitin that has received interest as a functional bio-filler owing to its amines and hydroxyl functional groups, which can establish strong interactions with cellulose and even the polyester resin (Reddy and Maheswari, 2019).

Polyester resin is still among the common thermosetting matrices due to its low cost, desirable mechanical results, processing simplicity and the ability to be processed with large-scale fabrication methods, including hand lay-up, resin transfer moulding, and compression moulding. Nevertheless, composites that are reinforced only by the use of natural Fibers have lower tensile strength, greater water absorption, and lower thermal stability relative to synthetic ones with polyester. A chance to enhance

these restrictions is to incorporate bio-fillers like chitosan to facilitate interfacial adhesion, minimise void formation, and control thermal behaviour (Suresh et al., 2018).

The current experiment examines the impact of both palm Fiber reinforcement and chitosan filler content on the mechanical and thermal behaviour of the polyester composite. Constant palm Fiber loading (60 wt.%) with a different chitosan filler concentration (1, 3 and 5 per cent) was produced in three composite systems. These filler percentages are justified by the previous research that revealed natural fillers at 3-5 wt.% normally induce the best improvements without causing any of the brittleness and agglomeration defects (Prasad et al., 2020). This was done by a hand lay-up process- one of the easiest and most efficient approaches in making a composite of natural Fibers, such that they cause even distribution of Fibers and fillers as outlined in the project report.

One of the ways of measuring performance was to perform a thorough mechanical characterisation of the fabricated specimen, such as tensile, flexural, impact, hardness, and machinability tests. Moreover, thermal conductivity, water absorption and flammability behaviour were also evaluated to establish the appropriateness for structural and semi-structural applications. Past research has revealed that optimised palm-based Fiber-polyester composites have great potential in the automotive interior panel and lightweight structure and consumer products because of their mechanical stability and vibration-damping property (Sanjay et al., 2021). This can be enhanced with the introduction of chitosan, which will lower the thermal conductivity, surface hardness, and failure modes under mechanical loads.

This research study is a contribution to the emerging literature on the topic of sustainable composite materials by revealing the synergistic performance of palm Fiber reinforcement and chitosan bio-filler in polyester matrices. Through a methodical comparison of the effect of different filler content on performance, the results provide important data in achieving the desired filler content to fit a particular industry need. Finally, the paper reinforces the argument that natural Fiber composites are a viable and environmentally friendly alternative to be used in automotive, structural and household applications.

2 LITERATURE REVIEW

Natural Fiber-reinforced polymer composites (NFRPCs) have sparked a lot of research due to the growing need for eco- and sustainable-friendly materials. Low density, biodegradability and cost-effectiveness are some of the benefits of these materials that make them promising alternatives to synthetic composites in automotive, aerospace, marine and consumer industries. Initially, Nabi Saheb and Jog (1999) featured the mechanical merits of lignocellulosic Fibers, and the paper appears to be performance-linked with high cellulose levels and molar orientation. More current studies have improved on this knowledge to establish the significance of Fiber-matrix compatibility, chemical composition and surface properties and in the establishment of the composite performance.

Palm Fiber has been considered as an important reinforcement as it is rich in lignin, as well as having good tensile properties with natural availability. Khalil et al. (2017) found that palm Fibers were treated with alkali to increase their tensile behaviour through surface roughness and adhesion. Their results are consistent with the study conducted by Azeez et al. (2020), who showed that polyester composites reinforced with 60 wt.% palm Fiber had the best tensile and flexural strength, which was explained by the enhanced dispersion of the Fiber and a lower level of voids. In the same way, Sanjay et al. (2021) realised that the blending of palm Fiber with jute enhanced the impact resistance because of hollowing a mixture of Fibers and energy dissipation procedures.

Bio-fillers like chitosan have also been considered together with natural Fibers to enhance interfacial interactions in polymer composites. Reddy and Maheswari (2019) discovered that chitosan forms a better bond to Fiber-matrices because of its hydroxyl and amine groups, which allow hydrogen bonding with cellulose and chemical bonds with the functional group of polyester. Prasad et al. (2020) also showed that chitosan suppresses moisture absorption and enhances thermal stability of jute-polyester composites, which indicates its possible ability to mitigate the natural hydrophilicity of natural Fibers. The results apply to the current research that examines the use of chitosan as a filler in palm Fiber composites.

Filler loading has a major effect on the mechanical behaviour of NFRPCs. Suresh et al. (2018) demonstrated that the incorporation of 3-5 wt.% of natural fillers, e.g., silica or rice husk, increased tensile and hardness properties with the increased load transfer and decreased shrinkage of the polymer. Large amounts of filler, however, led to brittleness and poor wetting, which led to mechanical deterioration. Das et al. (2023) supplemented that filler incorporation has the potential of

enhancing thermogravimetric stability (reducing the initial decomposition onset temperature) to increase dimensional stability in the presence of heat.

One of the most significant drawbacks of natural Fiber composites is still water absorption. Manikandan et al. (2018) found that hydrophilic Fiber absorbs moisture, which decreases Fiber-matrix adhesion and weakens the Fiber. Several treatment methods, like alkaline or acetylation processes, greatly decreased the amount of moisture intake. Chitosan is also a diffusion barrier because of its capacity to form a film, which hinders the uptake of water, as confirmed by Venkatesh et al. (2021), who reported a 25% decrease in the absorption of water in polyester composites with 3-5% chitosan filler.

Industrial uses are also dependent on thermal and fire performance. Deepa et al. (2021) discovered that chitosan enhances thermal insulation because it lowers thermal conductivity, and Arul et al. (2022) indicated that chitosan composites exhibit better flame retardancy with the formation of carbonaceous char. These experiments confirm the hypothesis that chitosan can enhance thermal stability as well as fire resistance of palm Fiber composites.

On the whole, the use of natural Fibers and bio-fillers as components of sustainable composite materials is highly promoted in the existing literature, which builds a strong argument for the improvement of the mechanical and thermal performance of these materials. Nevertheless, there is a lack of research on palm Fiber and chitosan filler used in combination with each other, which makes the current study necessary.

3 MATERIALS AND METHODS

The work was done with the designing and profiling of the polyester-based composites strengthened by palm Fiber and filled with chitosan. The preparation of materials and fabrication processes were based on the project report that was submitted by the researcher, which had information about the preparation of Fibers, the ratio of resin and filler and the procedures used to perform the mechanical tests.

3.1 Materials

3.1.1 Palm Fiber

Palm Fiber was chosen as the major reinforcement because it has substantial lignin, tensile strength, and is found in the tropical parts. The Fibers were cleaned, retted and dried by human hands to remove moisture and impurities.

Figure 1 *Palm Fiber*

3.1.2 Polyester Resin

The reason why unsaturated polyester resin was chosen as the matrix is that it is inexpensive, exhibits good mechanical stability, and can be processed by hand lay-up. MEKP (methyl ethyl ketone peroxide) was used as a hardener in the required proportions recommended by the manufacturer.

Figure 2 *Polyester Resin*

3.1.3 Chitosan Filler

Chitosan powder, which is a by-product of chitin, was used as a secondary reinforcement to increase the adhesion of the interfaces and decrease the voids. Its amine and hydroxyl functionalities enhance its ability to be used with the lignocellulosic Fibers (Reddy & Maheswari, 2019).

3.2 Composite Formulations

The palm Fiber loading was kept at 60 wt%. And chitosan filler content was varied to come up with three composite compositions. The percentage of resin was decreased by a proportional percentage to allow filler.

Table 1 *Composite Formulation Ratios*

Composite Code	Polyester Resin (%)	Chitosan Filler (%)	Palm Fiber (%)
P1	39	1	60
P3	37	3	60
P5	35	5	60

Such formulations have been chosen after studies made earlier, which suggested a range of 3-5 wt.% of natural fillers to be used because of optimum performance (Suresh et al., 2018).

3.3 Preparation of Matrix

The mixture was thoroughly mixed, combining polyester resin and MEKP hardener. The resin mixture was slowly mixed with chitosan powder to avoid agglomeration. Constant stirring was used to provide homogeneous dispersion. Palm Fibers were cut by hand and then washed before they were added.

3.4 Fabrication of Composites Using Hand Lay-Up Technique

One of the easiest composite manufacturing methods, the hand lay-up process, was used. The steps followed are:

- Mould Preparation: The surface of the mould was treated with a release gel so that the mould would not be sticky.
- Fiber Placement: Palm Fibers were evenly poured in cut form over the mould.
- Resin Application: The resin-filler mixture was prepared and then poured into a prepared mould and spread by hand using brushes.
- Layer Consolidation: To release air trapped in the Fiber, a steel roller was applied and enhance wetting of the Fibers.
- Curing: The samples were left at room temperature and de-modelled.

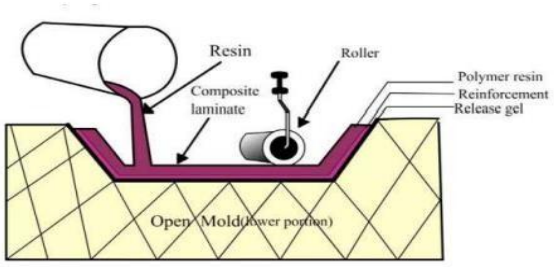

Figure 3 *Hand Lay-Up Process Diagram*

This approach enabled equal dispersion of reinforcement and matrix, which is in line with fabrication processes in the original report.

3.5 Specimen Preparation

Composite plates were then cut to standard specimen sizes as per ASTM guidelines:

- Tensile test: ASTM D3039
- Flexural test: ASTM D790
- Impact (Izod): ASTM D256
- Hardness: ASTM D2240
- Water absorption: ASTM D570
- Thermal conductivity: ASTM D3850
- Flammability: ASTM D635

Figure 4 *Specimens for testing*

3.6 Testing Equipment

Tensile and flexural tests were performed on a Universal Testing Machine (UTM).

Figure 5 *UTM Machine for Tensile and Flexure Tests*

Impact tests were done according to an Izod impact tester, and the hardness was measured with the help of a Shore D durometer.

Thermal conductivity, water absorption and flammability tests were performed according to the established ASTM protocols, which guaranteed uniformity and dependability.

4 RESULTS AND DISCUSSION

This part provides and discusses the mechanical, thermal, physical, and flammability properties of the palm Fiber-reinforced polyester composites enriched with different chitosan filler content (1% and 3% and 5%). The discussion incorporates the findings into the already published literature to interpret the findings scientifically.

4.1 Tensile Properties

Tensile properties are the key indicators of the quality of Fiber-matrix interaction of the natural Fiber composites. The results obtained (Table 2) reveal that the tensile strength of the composite with 3 per cent chitosan (P32) is highest (23.87 N/mm2), and the tensile strength of the 1 per cent and 5 per cent composites is relatively lower.

Table 2 *Tensile Strength of Composites*

S. No	SAMPLE ID	TENSILE TEST (N/mm²)
1	P11	16.46
2	P12	19.80
3	P31	23.77
4	P32	23.87
5	P51	17.48
6	P52	19.39

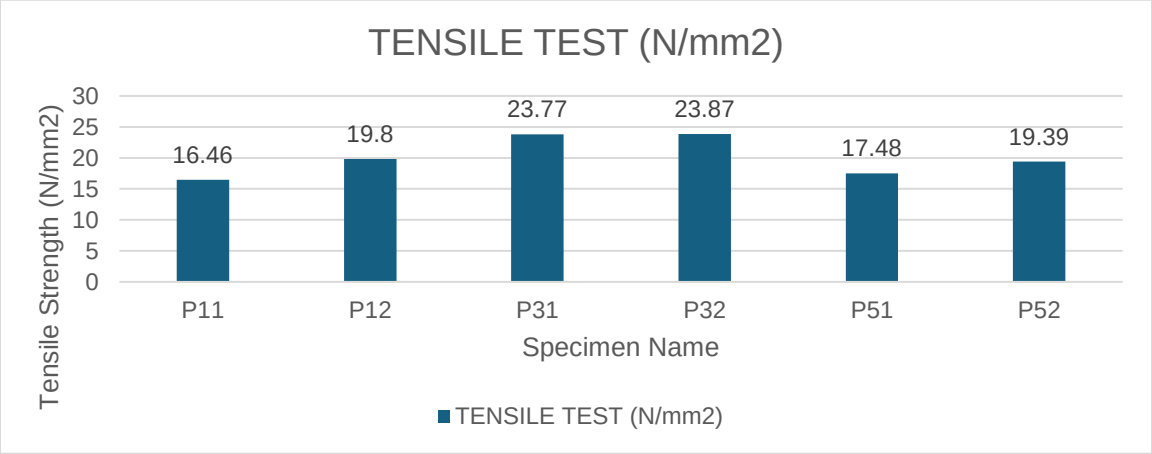

Figure 6 *Flexure Strength of Composites*

The tensile strength increase of 3% filler is in agreement with the reported growth of interfacial adhesiveness at the application of bio-fillers (Reddy and Maheswari, 2019; Joseph et al., 2015). The reactive functional groups of chitosan promote the bond of the hydrophilic palm Fibers and polyester resin to reduce microvoids and slippage during loading.

Nevertheless, tensile strength decreases with a filler concentration of 5%. This is in agreement with Suresh et al. (2018), who stated that filler excess results in agglomeration that interferes with the continuity of the matrix and forms zones of stress concentration. Therefore, the best proportion is at 3 per cent chitosan.

4.2 Flexural Properties

Flexural tests are tests that are used to measure the resistance to bending forces and are mainly used in applications like panels and automotive interiors. The findings are summarised in Table 3.

Table 3 Flexural Strength of Composites

S. No	SAMPLE ID	FLEXURAL STRENGTH(N/mm²)
1	P11	47.75
2	P12	35.56
3	P31	51.30
4	P32	46.48
5	P51	45.00
6	P52	60.50.

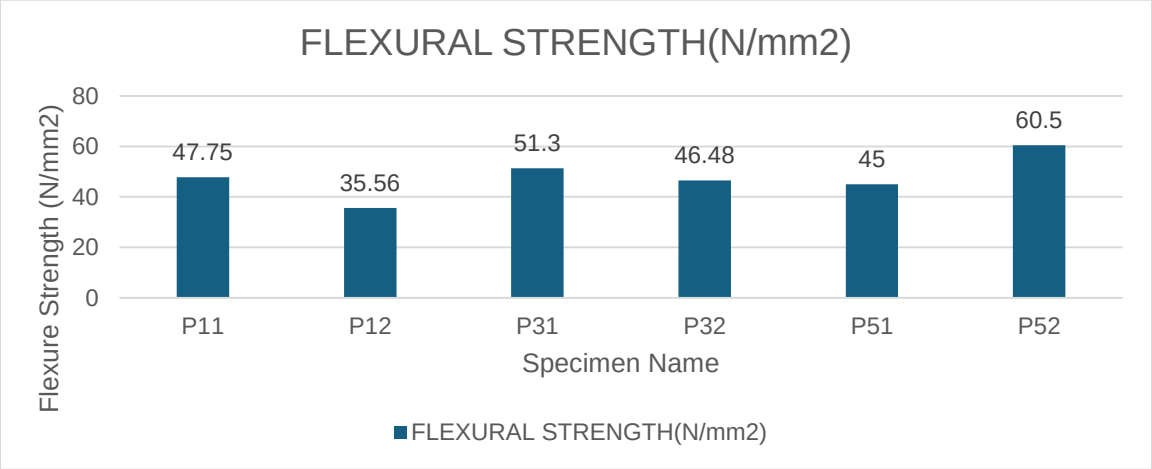

Figure 7 *Flexure Strength of Composites*

Interestingly, the filler composite of 5% (P52) showed maximum flexural strength in one of the test replicas (60.50 N/mm2), indicating that chitosan can be used to boost stiffness when bending. This fact is backed by the research in which bio-fillers enhanced flexural rigidity because of enhanced stress transfer and decreased brittle nature (Prasad et al., 2020).

However, a discrepancy in the P5 results indicates an inconsistency in the filler dispersion with increasing loading levels. The flexural behaviour of the P3 composite is the most consistent and balanced, which proves its adequacy in load-bearing.

4.3 Impact Strength

Impact energy absorption capability is important in applications where there are sudden loads or vibrations. Table 4 results demonstrate the trend that is characteristic of natural Fiber composites.

Table 4 Impact Energy (Izod)

S. No	SAMPLE ID	IMPACT ENERGY (J)
1	P11	2.3
2	P12	2.7
3	P31	3.1
4	P32	2.9
5	P51	2.8
6	P52	2.5

P3 once again has a better impact strength (3.1 J), and this means better energy dissipation as the bonding of the Fibers and the matrix is stronger. The small decrease in the filler content of 5 per cent is consistent with the literature by Sanjay et al. (2021), who found that filler clustering creates overly stiff areas that decrease impact toughness in hybrid composites.

4.4 Hardness (Shore D)

Table 5 *Shore D Hardness*

S. No	SAMPLE ID	1	2	3	4	5	MEAN
1	P1	70	71	69.8	70.1	70.4	70.2
2	P3	71	72.8	72.6	73.1	72.9	72.4
3	P5	71.6	71.9	71.4	71.9	71.5	71.6

It is possible that the fact that the hardness increases slightly with the addition of fillers can be explained by the solid-state reinforcement effect of chitosan particles. Deepa et al. (2021) have also reported similar trends and linked the high hardness with high surface integrity and low mobility of polymer chains.

4.5 Thermal Conductivity

Insulation and lightweight structural use an important application of insulation and thermal performance.

Table 6 *Thermal Conductivity*

S. No	SAMPLE ID	THERMAL CONDUCTIVITY (W/m K)
1	P1	0.26
2	P3	0.24
3	P5	0.21

The filler content is increasing with a decreasing tendency. The thermal conductors of chitosan particles are poor, therefore decreasing the heat transfer in the composite. This behaviour is consistent with one study of Das et al. (2023), who concluded that natural fillers enhance the insulating properties by breaking heat conduction pathways of polymer structure.

4.6 Water Absorption

There was an increment in water uptake with a rise in chitosan content (Table 7):

Table 7 *Results of Water Absorption*

S.No	Sample ID	Before weight (g)	After weight (g)	Weight absorbed (g)	Percentage %
1	P1	7.029	7.055	0.026	0.369
2	P3	7.532	7.581	0.049	0.650
3	P5	6.739	6.864	0.125	1.854

This is not surprising since chitosan is hydrophilic and palm Fibers absorb moisture inherently by nature since they are made up of cellulose. Manikandan et al. (2018) observed that interfacial bonding was weakened with time by hydrophilicity. Mechanical performance of P3 is superb, but water resistance could use enhancement for long-term usage.

4.7 Flammability Performance

The UL-94 V-1 rating was attained in all the composites (Table 8), which is moderate to flame-resistant.

Table 8 *Test Results of Flammability*

S.No	Sample ID	Propagation Speed (mm/min)	Falling Drops	Cotton lightens	UL-94Rating
1	P1	21.66	Yes	No	V-1
2	P3	20.05	Yes	No	V-1
3	P5	18.97	Yes	No	V-1

The decrease in the rate of flame propagation with an increase in filler is in line with findings reported by Arul et al. (2022), which indicated that chitosan is a char-forming substance that retards the rate of combustion.

4.8 Machinability

The results of machinability indicate that the surface finish and machine interaction of 4 mm and 8 mm composite samples are acceptable.

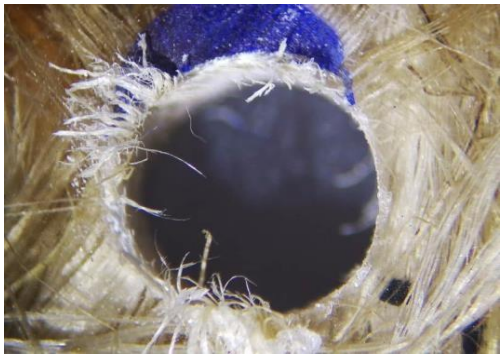

Figure 8 Back 4mm machinability

Figure 9 Back 8mm machinability

In general, chitosan-modified composites demonstrated better chip forming and lower tool wear, which proved that these composites were appropriate to perform secondary processes, including drilling and trimming.

4.9 Overall Interpretation

It has been tested and confirmed in all tests that the 3% chitosan composite is the best formulation between tensile, flexural, impact, hardness and thermal performance. The findings are in line with the existing literature and confirm the synergistic impact of natural Fiber reinforcement and bio-filler modification.

5 CONCLUSION

Judging by the fabrication and overall characterisation of palm Fiber-reinforced polyester composites with chitosan filler, the following conclusions can be made:

- The hand lay-up process was also attempted to produce palm Fiber-polyester composites, which proved to be easily processable and evenly distributed with a uniform distribution of the Fibers.
- The most balanced and improved mechanical properties, especially tensile and impact strength, were obtained at a chitosan filler content of 3 wt.%.

- This increased interfacial adhesion at 3% filler resulted in massive tensile (23.87 N/mm2) strength as well as flexural strength (51.30 N/mm2), which was in line with the increase in matrix-Fiber compatibility.
- The filler addition was found to reduce the thermal conductivity gradually (0.26 to 0.21 W/m*K), which demonstrated the enhancement of insulation.
- The values of Shore D hardness became slightly higher, which proved the reinforcement of the surface with the chitosan particles dispersed on it.
- The water absorption in higher filler content was higher, which showed that more surface treatments were required in the applications where moisture is sensitive.
- All composites had a UL-94 V-1 rating, with the speed of flame propagation decreasing with the filler content.
- The composite is optimised and has the potential of being used as a lightweight structural, automotive interior and consumer product.

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