Investigation Into Natural Material Integration for Improved Mechanical Performance in Glass-Jute Fibre Hybrid Composites

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Abstract. Natural fibres have attracted the interest to engineers, researchers, professionals and scientists all over the world as an alternative reinforcement for fibre reinforced polymer composites, because of its superior properties such as high specific strength, low weight, low cost, good mechanical properties, non-abrasive, eco-friendly and bio-degradable characteristics. The growing demand for sustainable and high-performance materials has led to increased interest in natural reinforcements for composite materials. This study explores the mechanical behaviour of hybrid composites made from glass fibre and jute fibre matrices, reinforced with two natural seed powders: Tamarindus indica (tamarind) and date kernel. The objective is to evaluate the feasibility and effectiveness of these natural additives in enhancing the mechanical properties of conventional fibre composites. The primary aim is to evaluate the effectiveness of these natural fillers in enhancing the tensile, compressive and impact properties of the composites. Specimens will be fabricated using the hand lay-up technique, employing epoxy resin and hardener in a 10:1 ratio as the binding matrix and subjected to series of Mechanical tests which include Tensile, Compression and Charpy impact testing. Each material will be tested and compared to baseline composites to see if any performance benefits result from the addition of natural reinforcements.

1 Introduction

Composite materials are being used more and more in engineering applications because of their special combinations of qualities, including low density, high strength-to-weight ratio and superior corrosion resistance [1]. In order to create a material with improved overall performance, two or more distinct ingredients—which may have different physical or chemical properties—are combined to create composite materials.

[2]. Because of their great mechanical strength, low weight and affordability, glass fibre reinforced composites in particular have become more and more well-liked. However, there is still a great deal of room to improve the mechanical qualities of these hybrid and recommended composites. Natural fillers could be an area for improvement. We have recently started looking into the use of natural seed powders, like date kernel seed powder and Tamarindus indica (tamarind) seed powder. [3-5]. Although natural fibers have a greater potential to improve the mechanical properties of the composite material, jute fibre and glass fibre composite matrices provide an additional opportunity to explore hybrid composites.Due to their fiber-like characteristics and favorable bonding behavior with polymers, natural fillers may improve several mechanical attributes. [6]. However, limited research has examined the use of Tamarindus indica or date-kernel powders and their role as reinforcement materials is still unclear. [7-9]. This gap highlights the need for detailed experimental studies on hybrid composites made with glass and jute fibers. [10-12].Natural fibers offer a more environmentally friendly substitute for synthetic reinforcements in addition to the possible performance advantages. [13]. Natural fibers are a viable option for more ecologically friendly composite materials because they are renewable, [14]. biodegradable and have minimal environmental impact, whereas synthetic reinforcements are usually [15]. non- biodegradable and require significantly more energy to produce.

2 Materials Selection

Glass fibre is widely used in the production of composite materials and is composed of tiny glass strands. Because of its exceptional mechanical strength and stiffness, outstanding electrical insulation qualities, lightweight design and resilience to chemicals and the environment, E-glass fibre is the most widely used type of glass fibre. Because of these qualities, it can be used in a wide range of industrial, marine and automotive applications Continuous or discontinuous glass fibers reinforced in a matrix make up glass fiber composites, also known as fiberglass. They are the most widely used composites due to several advantages:

- Ease of fabrication: Molten glass can be easily drawn into high-strength fibres and processed using various manufacturing techniques.
- High specific strength: Strong fibres provide an excellent strength-to-weight ratio.
- Chemical resistance: Inert in plastics, making them suitable for corrosive environments.

Advantages: Low cost, high tensile strength, excellent chemical resistance and good electrical insulation. Disadvantages: Low tensile modulus, relatively high specific gravity, susceptibility to abrasion (reducing strength), low fatigue resistance and high hardness causing wear on dies and cutting tools.

The transportation industry increasingly uses glass fibre-reinforced polymers (GFRP) to reduce vehicle weight and improve fuel efficiency. Among glass fibres, E-glass and S-glass are the most common in the FRP industry. E-glass is the most widely used due to its low cost and good performance, making it ideal for general applications.

Table 1. Typical Composition of Glass Fibres (inweight %) (Mallick,1988).

Glass fiber type	SiO_2	Al_2O_3	CaO	MgO	B_2O_3	Na_2O
E-glass	54.5	14.5	17	4.5	8.5	0.5
S-Glass	64	26	-	10	-	-

fabric is a natural textile fibre derived from the jute plant. Among its botanical varieties, Corchorus olitorius (white jute) is commonly used for fabric production. However, Corchorus capsularis (tossa jute) is considered superior in quality, though it is more challenging to cultivate.

2.1 Jutefibre

Cotton is the most widely produced plant-based fibre, but jute ranks a close second. While less popular in Western countries, jute is a major textile fibre in India and neighboring regions. Jute plants can grow over 10 feet tall and their fibres are harvested as long, continuous strands, making them among the longest natural textile fibres in the world.

Jute cultivation requires conditions like those for rice. It thrives in warm, humid regions with annual monsoon seasons. The crop cannot grow in hard water and an ambient humidity level of around 80% is essential for optimal production.

In the present work the both glass fibre and jute fibre were used in their received condition without any chemical surface treatment such as alkali treatment and acetylation. The objective was to assess the influence of natural filler addition under identical fabrication conditions.

Fig.1 preparation of glass Jute Fibre

2.2 Epoxy Resin

Epoxy resin is a thermosetting polymer widely used as a matrix material in composites. It consists of two components: a resin and a hardener, which chemically react when mixed, forming a hard and durable material. Epoxy is well-known for its excellent adherence, particularly to glass fibers and for significantly enhancing the composite's strength and structural soundness.Epoxy resins are the most widely used resins in composite manufacturing, offering a variety of resin–hardener combinations to suit different applications. The highly resistant to chemicals and show little shrinking when cured. Epoxy is produced when epichlorohydrin and bisphenol react.

Advantages of epoxy matrices
- No volatile matter issue during curing
- Minimal shrinkage during cure

- Outstanding resistance to chemicals and solvents
- Solid adhesion to various fillers and substrates

Disadvantages:

- Relatively high cost
- Longer curing time.

2.3 Tamarindus indica seed powder

The seeds of the evergreen Tamarindus indica tree are extracted to make Tamarind Kernel Powder (TKP). The glucose and gum in the seed kernel, which are often considered as waste, are ground into a fine powder. due to its high viscosity and superior water absorption, TKP is often used as a binder in the pharmaceutical industry and as a thickening agent in textile sizing and printing.

Tamarind seedsproduct of tamarind fruit which are rich in protein, carbohydrates, fibre and oil, making them a valuable food additive. They are used in jelly preparation and serve as a good source of dietary fibre and minerals, contributing to tamarind’s popularity as a functional food ingredient.

Properties of tamarindus indica seed powder

The material consists primarily of D-mannose and D-galactose units and appears as a creamish-white, odor-free powder. The product contains a moisture level ranging between 6% and 12%. Its crude fibre content is maintained within 1–2%, while the protein content varies from 10% to 20%.

When prepared as a 3% aqueous solution, the viscosity is approximately 2800 centipoise (CPS), indicating strong thickening characteristics. The color of the powder is light cream in appearance. A 5% slurry of the material exhibits a near-neutral pH in the range of 6.0 to 7.0.

Particle size distribution analysis shows complete passage (100% w/w) through a 100-mesh sieve. Approximately 99% (w/w) passes through both 200-mesh and 300-mesh sieves, confirming its fine particle size. The ash content is controlled within 1–3%.

Tamarind Kernel Powder demonstrates excellent water absorption capacity and maintains high viscosity across a wide pH spectrum, making it suitable for applications requiring stable thickening performance under varying conditions.

It is a natural ingredient commonly used in cooking and baking and is widely available in local markets in various forms— dried, ground, or powdered. The most common form is tamarind seed flour, which is derived from fresh or frozen seeds. This powder serves as an excellent stabilizer in food preparation.

2.4 Dates kernel powder

Date kernels (seeds), like date fruits, offer numerous health benefits and are rich in nutrients, like other kernels such as avocado, mango, apricot and apple seeds. Date seed powder is typically produced by roasting or burning the kernels and then grinding them into fine powder.Numerous beneficial substances, saturated and unsaturated fatty acids and vital minerals like potassium, calcium, cadmium and zinc are present in this powder. Stearic and palmitic acids are the main types of saturated fatty acids, whereas linoleic and oleic acids are unsaturated fatty acids that block the enzyme 5α-reductase.

3. FabricationTechniques

A composite material called glass fibre reinforced polymer (GFRP) is made up of glass fibres embedded in a polymer matrix. GFRP components can be made using a variety of methods, each with unique potential advantages and disadvantages based on the intended mechanical or material qualities and possible uses. Jute fibres embedded in a polymer matrix serve as the reinforcing agent in Jute Fibre Reinforced Polymer (JFRP). Similar to GFRP, jute composites can be made using a variety of techniques, each with pros and cons that are impacted by environmental, mechanical and cost considerations.

Here are some different approaches.

Hand Lay-Up: Using a roller to manually insert glass fibers into a mold, followed by resin that is rolled into the fibres, the hand lay-up method is one of the earliest and most basic methods for fabricating GFRP. Until the desired thickness is reached, this layering process is repeated. Although this method is very low-cost and requires minimal equipment, it is labor- intensive and may result in a lower-quality product because it is a manual process.

Spray-Up: This method, which calls for a spray gun, applies a mixture of resin and chopped glass fibres to a mold's upper surface. Spray-up is a good manufacturing technique for large or shaped molded components because it is significantly faster. However, in addition to any surface finishing required to achieve the required quality of the manufactured product, spray-up may result in irregularities in the validated fiber distribution.

Resin Transfer Molding (RTM): In this approach, glass fibers are positioned in the mold prior to resin introduction and pressure is applied once the mold is closed to drive the resin uniformly through the reinforcement. Although the tooling requirements are substantial and raise production expenses, the technique supports the manufacture of finely detailed parts with excellent surface appearance.

With the vacuum infusion method, the dried glass fibres are first arranged inside the mould. The fibre pack is then consolidated by drawing a vacuum. The resin enters the cavity and penetrates the fibres at this negative pressure. The cost of the required infrastructure is still a significant disadvantage given that the method is effective and consistently generates parts with minimal waste.

Filament Winding - Glass fibres are steered onto a rotating mandrel in an established winding order, and resin is used either before or during the laydown. After drying, the mandrel is removed to expose a lightweight, rigid structure. Consistent mechanical quality is provided by the method, but it has the disadvantage of expensive equipment.

Pultrusion - This process creates pieces with a consistent cross-section all the way along by constantly drawing glass fibres that are wet with resin through a heated forming die. While it has low waste and good consistency, its geometry options are restricted to straight profiles, and the equipment required is expensive and specialised.

The choice of the hand lay-up technique for this project is

Cost-Efficiency and Simplicity, the process is cost-effective and simple, only basic tools and making it accessible without advanced manufacturing infrastructure.

Material Flexibility, because the method works with a broad range of reinforcement materials, with it readily enables the inclusion of natural fillerslike seashell, crab-shell and eggshell powders

Control Over Fabrication Parameters,this method provides hands-on control of both fibre placement and resin flow, which in turn shape the composite's final mechanical properties.

Ease of Use and Accessibility, the method ease allows newcomers to learn it quickly, enabling extensive use in teaching and research contexts that lack specialized equipment.

In conclusion, the hand lay-up method was selected by the researchers due to its low cost, adaptability with regard to natural reinforcements and simplicity of use. Making it the ideal and most practical choice for producing composite samples for mechanical testing.

4. MaterialPreparation

4.1 Preparation of Natural Reinforcement Particles:

a)Collection and Cleaning: To eliminate contaminants or impurities that could lower the quality of the finished composite, date kernel and tamarindus indica seeds were gathered and cleaned.

b)Crushing and Sieving: The cleaned seeds were crushed and sieved using a 75 µm mesh sieve to obtain fine particles with controlled sieve-based average size. This eliminated any large particles or undesired debris and produced a consistent particle size.

Fig.2 Preparation of Natural Reinforcement Particles

Step 1

- Glass and jute fibre woven fabrics were each marked to dimensions of 30 × 30 cm.
- The glass fabric was cut into 9 pieces and the jute fabric into 6 pieces using scissors.

Step 2

- The jute fibre fabric was cut to the required dimensions.
- Molds were prepared by applying a layer of wax to their surfaces to prevent the composite mixture from sticking.
- A layer of glass fibre fabric was then carefully placed inside the mold.

Step 3

- Epoxy resin and hardener were mixed in a 10:1 ratio (300 ml resin: 30 ml hardener).
- 30 g of each natural filler was added separately to the epoxy-hardener matrix (300 ml epoxy + 30 ml hardener), to approximately 7 wt% filler loading. The hybrid specimen which 15 g of Tamarindus indica seed powder and 15 g of date kernel powder were used to maintain identical total filler content.
- A hybrid specimen was also made using 15 g of Tamarindus indica and kernel seed powders.

Step 4

- The mixture was brushed to remove air bubbles and poured into molds for 24-hour curing at room temperature, ensuring even distribution.
- For one specimen, 3 layers of glass fibre and 2 layers of jute fibre were placed alternately, with each layer brushed evenly with the resin mixture.

Step 5

- A weight was placed on top of two flat surfaces to hold the composite in place during curing.
- The process was repeated to prepare three specimens.

The selected input enablers and their chosen levels are listed in Table 1. The ECMM set up used in the performance of drilling micro hole was depicted in figure 1.

Step 6

- After 24 hours, the cured composite specimens were carefully removed from the molds.

Step 7

- The cured composite specimens were marked and cut into two different sizes.
- For tensile tests, specimens were cut to 250 × 27 mm.
- For the impact test, specimens were cut to 80 × 12 mm.

5. Results and Discussion

Mechanical tests were conducted under identical experimental conditions for all fabricated specimens, and the reported values represent comparative observed results

5.1 Tensile Test

5.1.1 Tensile Performance of GFRP & JFRP with Tamarindus indica seed reinforcement

Fig.3 Load-Displacement Curve of Tamarindus indica seed (tensile test)

Tensile test results showed that the crab shell reinforced composite achieved an ultimate tensile load (UTL) of 13.99 kN, indicating its maximum load capacity before failure.

The Tamarindus indica seed-reinforced composite achieved a UTS of 168 MPa, indicative of its high tensile strength.

The study shows that including Tamarindus indica seed powder strengthens the composite in tension, making it a viable option for uses where both durability and high load-bearing capability are essential.

5.1.2Tensile Performance of GFRP & JFRP with Date Kernel Seed reinforcement

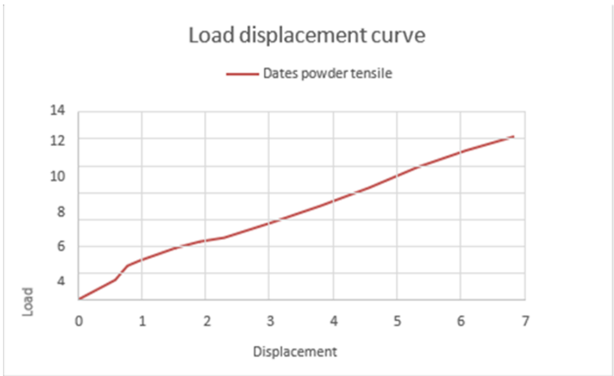

Fig.4 Load-Displacement Curve of Dates Kernel Seed (tensile test)

Tensile evaluation revealed that the composite containing date-kernel particles reached an ultimate tensile load (UTL) of 12.77 kN, which is the maximum load applied before the specimen failed. Its ultimate tensile strength (UTS) was measured to be 154 MPa, reflecting the highest stress sustained at fracture and the material’s resistance to tensile deformation.These results recommend that the addition of date kernel seed particles enhances the composite’s tensile response, which is leading to improved strength and a greater ability to support applied loads.

5.1.3 Tensile Performance of GFRP & JFRP with hybrid reinforcement

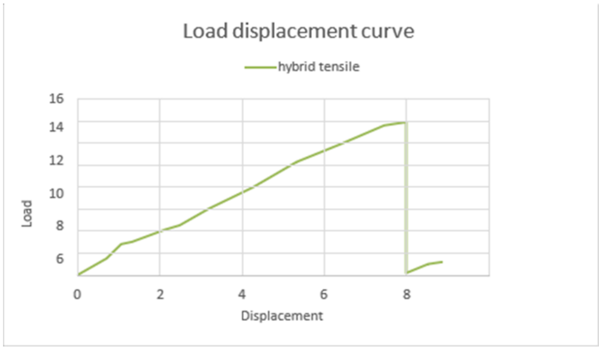

Fig.5 Load-Displacement Curve of hybrid (tensile test)

Tensile-test load–displacement curves showed that the hybrid composite containing Tamarindus indica and date kernel seed powders performed well mechanically. It continued a UTL of 14.04 kN before failure and its UTS was recorded as 172 MPa, indicating the stress level at which the fracture occurred. By showing how the composite behaved under increasing loads, the load-displacement curves offered a practical way to quantify and comprehend the material properties of the composite under applied tensile loads. The fracture point and areas of elastic and plastic deformation were indicated by the load-displacement curves. When evaluating structural performance, this analysis enables one to investigate properties of ductility, stiffness and resistance to deformation.

The findings demonstrate that hybrid reinforcement significantly improves composites' satisfactory tensile performance and establishes the hybrid composite as a material that works well in high-performance applications that call for durability and strength.

5.1.4 Comparison of all specimens

Among the four tested specimens, the hybrid composite demonstrated the highest Ultimate Tensile Load (UTL) at

14.04. With a UTL of 13.99, the composite reinforced with Tamarindus indica seeds came in second and the composite containing dates seeds finished much lower at 12.77.

Ultimate Tensile Strength (UTS) Comparison:

The UTS values show significant differences in values among the specimens. The hybrid composite gave the best UTS measure, achieving a UTS of 172. In second, the composite with Tamarindus indica seeds had a UTS of 168. And finally, the composite with dates seeds had the worst measure at 154.

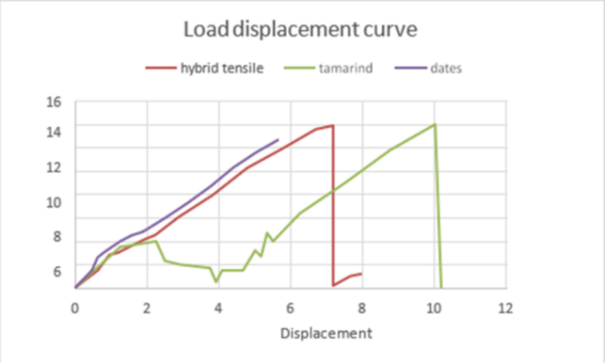

Fig.6 Comparison of all specimens (tensile test)

5.2 Compression Test

5.2.1 Compression Performance of GFRP & JFRP with Tamarindus Indica seed reinforcement

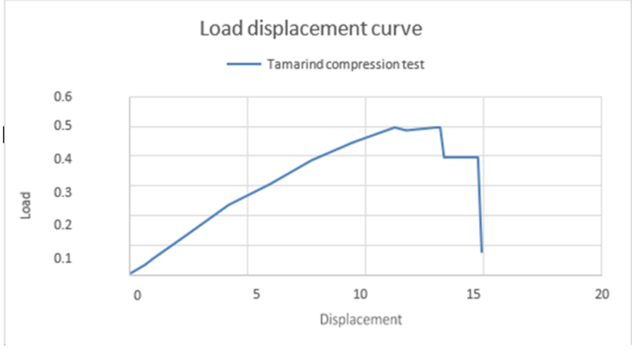

Fig.7 Load-Displacement Curve of Crab shell (compression test)

The behavior of the material under compressive forces was revealed by the load-displacement curve that was obtained from the compression test. The material reached a failure load of 0.50 kN and exhibited a tensile strength of 6 MPa.

Such measurements offer insight into how Tamarindus indica seeds fight applied forces and contribute to the broader mechanical profile of this natural material.

5.2.2 Compression Performance of GFRP & JFRP with Date Kernel Seed reinforcement

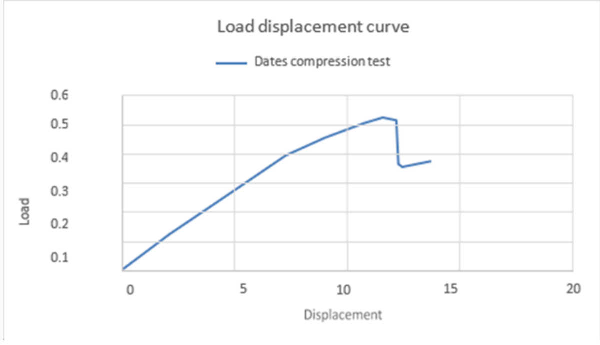

Fig.8 Load-Displacement Curve of Date Kernel Seed (Compression test)

Relevant data about the behaviour of the composite under increasing compressive forces has been shown by the load-displacement curve produced during the compression test. For the sample, a UTS of 6 MPa and a UTL of 0.47 kN were observed. The ability of the composite to tolerate compressive displacement a crucial quality for structural applications is reflected in this performance. The results improve the understanding of how date kernel particles impact compressive strength.

5.2.3 Compression Performance of GFRP & JFRP with Hybrid reinforcement

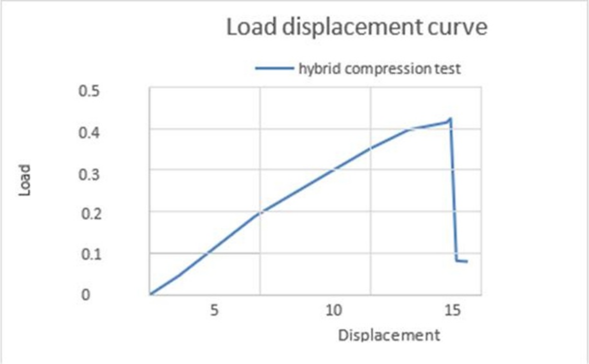

Fig.9 Load-Displacement Curve of Hybrid (compression test)

A load-displacement profile generated during the compression test showed the specimen's response to an increase in applied load. The Ultimate Compressive Strength (UCS) and Ultimate Compressive Load (UTL) have been identified by analysis of this curve.

The hybrid composite's compressive strength was 7 MPa, and it broke under a force of 0.52 kN. These results provide insight into the material's behaviour under compressive pressure and suggest that it could be utilised in parts where compression resistance is crucial.

5.2.4 Comparison of all Specimen

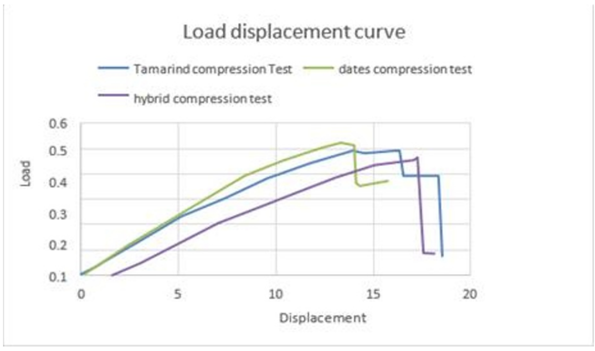

Fig.10 Comparison of all specimens (compression test)

Analysis of the load–displacement data attractions several trends in the mechanical behaviour of the composites:

- The hybrid material reached the highest Ultimate Compressive Load (0.52 kN), indicating improved resistance to compressive failure and its measured UTS remained 6 MPa.
- The date-kernel composite failed at 0.47 kN, while the Tamarindus indica-based composite reached 0.50 kN; both recorded a UTS of 6 MPa, suggesting similar tensile responses.
- Taken together, the results imply that combining the two natural fillers in a hybrid formulation offers a modest advantage in compressive performance without altering tensile strength.

5.3 Microscopic Examination

5.3.1 Microscopic Tamarindus Indica seed reinforcement

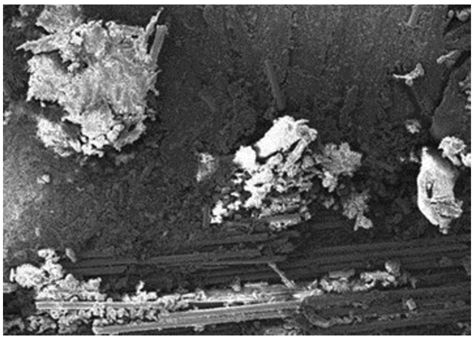

Fig.11 Microscopic Tamarindus Indica seed reinforcement

Microscopic Examination

The hybrid composite reinforced with Tamarindus indica seeds, which uses glass fibre reinforced polymer (GFRP) and jute fibre reinforced polymer (JFRP), can be examined under a microscope to reveal important details about its microstructural characteristics. Scanning Electron Microscopy (SEM), which offers accurate imaging of the composite surface, was used to carry out this investigation. When the right magnification and lighting techniques are applied, the SEM analysis enables the assessment of the surface morphology, fibre-matrix adhesion, particle dispersion and composite homogeneity. The results are crucial for assessing the hybrid composite's behaviors and structural performance under mechanical load.

5.4.1 Microscopic Date Kernel seed reinforcement

Fig.12 Microscopic Date Kernel Seed reinforcement

Microscopic Examination

SEM analysis of the composite reinforced with date-seed particles revealed how the material is structured at the microscale, including the distribution of particles and the condition of the surface.

The images showed the presence of voids and local surface disturbances, which could affect mechanical behaviour. Measuring these features helps control whether the composite was produced uniformly and whether its internal structure aligns with expected performance.

5.4.2 Microscopic Hybrid material reinforcement

Fig.13 Microscopic Hybrid Material reinforcement

Microscopic Examination

To improve comprehend the hybrid composite reinforced with Tamarindus indica and date-kernel powders in a GFRP/JFRP matrix, microscopy was done. Particle distribution, surface characteristics, and its overall homogeneity were all investigated using high-magnification SEM imaging.

The seed particles were comparatively well distributed throughout the fiber-reinforced matrix, as indicated by the micrographs, indicating that the fillers and the surrounding polymer interacted satisfactorily. The structural performance of the composite is improved by this even dispersion, which facilitates efficient stress transfer.

6. Summary and Conclusions

6.1 Summary ofthe Present Research Work

This study examined the potential of date kernel and Tamarindus indica seed powders as sustainable reinforcing elements for polymer composites. Knowing how these natural fillers affect the behaviour of composites constructed with glass and jute fibres was the primary goal.

Because GFRP and JFRP laminates are frequently used in lightweight structural applications and have reliable mechanical performance, both kinds of seeds were ground into fine powders and added to these. To produce a similar set of natural-fibre materials, the work was done in two stages: initially, the seed powders were mixed with glass-fibre laminates, and then they were incorporated into jute-fibre composites. To guarantee consistency, the same compression-molding procedure was used to create each sample.

Tensile and impact tests were amongst the mechanical tests that were completed, and results were in contrast to unreinforced control samples. A number of characteristics were improved by the inclusion of seed powders: the JFRP samples absorbed more energy at impact, while the GFRP composites showed greater tensile and performance.

The results show that date kernel and Tamarindus indica seed powders can function as efficient, sustainable reinforcing fillers. They are excellent candidates for the creation of future bio-composites since they not only improve crucial mechanical properties but also mix well with matrices of glass and jute fibre.

In order to improve performance even more, additional research might look at other filler quantities, modify processing parameters improve composite compositions. Considering the increasing need for sustainable high-performance materials in industries like construction, automotive engineering and lightweight design, these results run engineers, researchers, and manufacturers with important direction as they move toward greener composite materials.

7. Scope For Future Work

- Upcoming work could look at additional natural fillerssuch as hemp, bamboo, or coconut-shell powderto compare their mechanical performance and environmental benefits with those used in this study.
- It would be valuable to investigate how different processing methods, such as resin transfer molding or compression molding, influence the strength, structure and overall behaviour of composites reinforced with natural particulates.
- Further research should also examine how well these composites insulate heat and absorb sound. Considerate these properties could open opportunities in packaging, automotive interiors and building materials.

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