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Development and Evaluation of Mechanical Properties of Bio-Degradable Grass Fiber Composite Reinforced with Shrimp Shell Powder for Sustainable Applications

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Abstract

Shrimp, a significant area of the seafood industry in terms of production, is exceeded by only prawn and salmon in terms of volume; its global annual production exceeds 4.4 million tons. India is a sea of shrimp production: the country recorded a record high production of 9 lakh tonnes (900,000 metric tonnes) of cultured shrimp in 2021. Andhra Pradesh was the major contributor to cultured shrimp culture, amounting to around 70% of the Indian output. The intensive system, notwithstanding the high-growth potential, is associated with environmental degradation, water pollution, and loss of diversity. This review addresses the status of shrimp production, the key environmental impacts of shrimp farming and efforts in the name of innovations for achieving sustainable growth. This paper discusses the mechanical properties and biodegradability of bio-degradable shrimp shell powder with grass fiber reinforced composites (BGFRPs). Bio-degradable shrimp shell powder is compressed through cold moulding process, and cylindrical samples are prepared for testing in compression and hardness properties of the cylindrical sample before its usage in the manufacturing of fiber reinforced composites. The composites were prepared using a hand layup method, with shrimp shell powder as filler material and epoxy resin supplemented with grass fibers to enhance mechanical strength. The tensile test, flexural test, impact test was performed in order to evaluate the performance of the BGFRPs compared to traditional composites. It depicts the methodologies adopted and principal findings with regards to Shrimp shell powder's mechanical properties and biodegradability, while also expounding on further possibilities for implications for sustainable material solutions for industry. It is inexpensive, very durable, and a greener alternative for a multitude of uses.

Keywords: Biodegradable, grass fiber, composite, shrimp shell powder, environmental impact, sustainable growth, cold moulding machine, fiber reinforced composites

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INTRODUCTION

The heightened popularity for the use of sustainable materials across different industries has triggered great interest in the use of biodegradable composites. Not only these materials provide an improvement in mechanical properties but also help the environment by reducing the use of materials which are not biodegradable. Out of a variety of natural fibers, grass fibers have proven to be a viable option since they are readily available, renewable and have strong mechanical properties. These fibers when used with biodegradable matrices make strong and eco-friendly composites [2].

Shrimp production accounts to a huge portion of seafood supply worldwide, with millions of tons being harvested every year. But, the cultivation of shrimps leads to an enormous amount of waste specifically sulfide wade that is generated which is the shrimp shells and are usually thrown away without being recycled causing ecological damage. There are two benefits associated with the use of shrimp shell powder in composite preparation it solves the problem of shrimp processing waste as well as it improves the mechanical strength of the biodegradable composites. Chitin and Calcium carbonate from shrimp shells are essential in ensuring the strength and durability of the composites [1].

Given that these composites are assessed with regards to their mechanical performance such as tensile, flexural and impact assessments, this study attempts to explore the possibilities these materials have in the development of eco-friendly products. The results will not only fill the gap regarding the body of knowledge on biodegradable composites of shrimp shells but will also enable the provision of alternative approaches to the waste problem in the shrimp processing industry in accordance with the principles of sustainability that are observed internationally [3].

In this research, we expect to illustrate that putting shrimp shell powder into grass fiber composites creates advanced green materials, which benefits industries and environmental protection.

LITERATURE REVIEW

The increase in interest towards the use of biodegradable composites stems from the serious situation regarding the ecological balance, which seeks to find certain materials that will have lesser negative effects on the environment. This literature review draws upon relevant studies on natural fiber composites as well as from the literature on the effect of shrimp shell powder on mechanical properties of biodegradable composites: a study of mediated composites. It has been proven through extensive research that fiber composites, particularly natural fibers reinforced in polymer matrices, enhance mechanical properties and reduce overall environmental impact of the said materials [1]. Natural Fiber composites are believed to be affected by a number of factors, the kind of fiber used, the length of fiber, the matrix material employed and the method of forming the fibrous structure. As an illustration, such investigations imply that composite materials containing strands of various natural fibers overlappingly can perform better than composites comprising only single fiber strands [2]. This indicates that the core idea behind the use of fibers in biodegradable composites is that when fibers are properly arranged and composed, performance can be built upon optimization strategies in a biodegradable composite.

The introduction of shrimp shell powder implies a new trend in composite application aimed at reinforcing the structure while at the same time responding to waste challenges. Chitin, calcium carbonate, and calcium carbonate are the primary components of shrimps shells. The chitin biopolymer is strong and biodegradable while calcium carbonate contributes strength to the polymer composite [1]. Studies show that the addition of shrimp shell powder into the polymer matrix can have noticeable improvements on the mechanical properties of the composites and hence make them useful for various applications. The mechanical properties of the composites which were reinforced with the shrimp shell powder were affected by the percentage of the powder that was used as well as the methods of processing. For instance, if the percentage of the shrimp shell powder in the composites is increased, then the tensile strength and hardness of the composite increases [4]. Even then, the type of matrix material such as the various resins and their combination with shrimp shell powder affect the functionality of the composite material.

For any biodegradable composites to be incorporated into commercial products, their mechanical properties are factors that need not be compromised. Different research got more attention in exploring the tensile strength, flexural strength, impact resistance and water absorption aspects of these materials. The results show that it is possible to manufacture biodegradable composites with quite competitive mechanical properties as in that of synthetic composites branches especially with proper utilization of reinforcement materials [1,2]. Perhaps, the most attractive feature of these composites is their biodegrability, which allows them to decompose completely and enhance the nutrient content of soils

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whilst reducing landfill waste [5]. Biodegradable composites are consistent with global sustainability initiatives, making them attractive for companies that focus on eco-friendly material manufacture. In conclusion, the existing literature points out the effectiveness of biodegradable grass fiber composites reinforced with shrimp shell powders as a better alternative for environmentally friendly materials. Using natural fibers and fillers coming from waste not only improves mechanical characteristics but also provides a solution for waste management issues. This study seeks to build on these studies by systematically examining the behavioral properties of these new composites, with the aim of advancing environmentally friendly material solutions.

MATERIALS AND METHODS

Materials

Lawn grass fibers were gathered from garden or from local agriculture fields. The fibers were collected, cleaned, and dried to remove any impurities and moisture content. The dried fibers were then aligned to achieve a uniform structure suitable for composite fabrication. Shrimp shells were obtained from a local seafood processing unit is shown in Figure 2(b). The shells were thoroughly washed to remove any residual meat and contaminants. After drying, the shells were ground using a mechanical grinder to obtain a fine powder is shown in Figure 2(c).

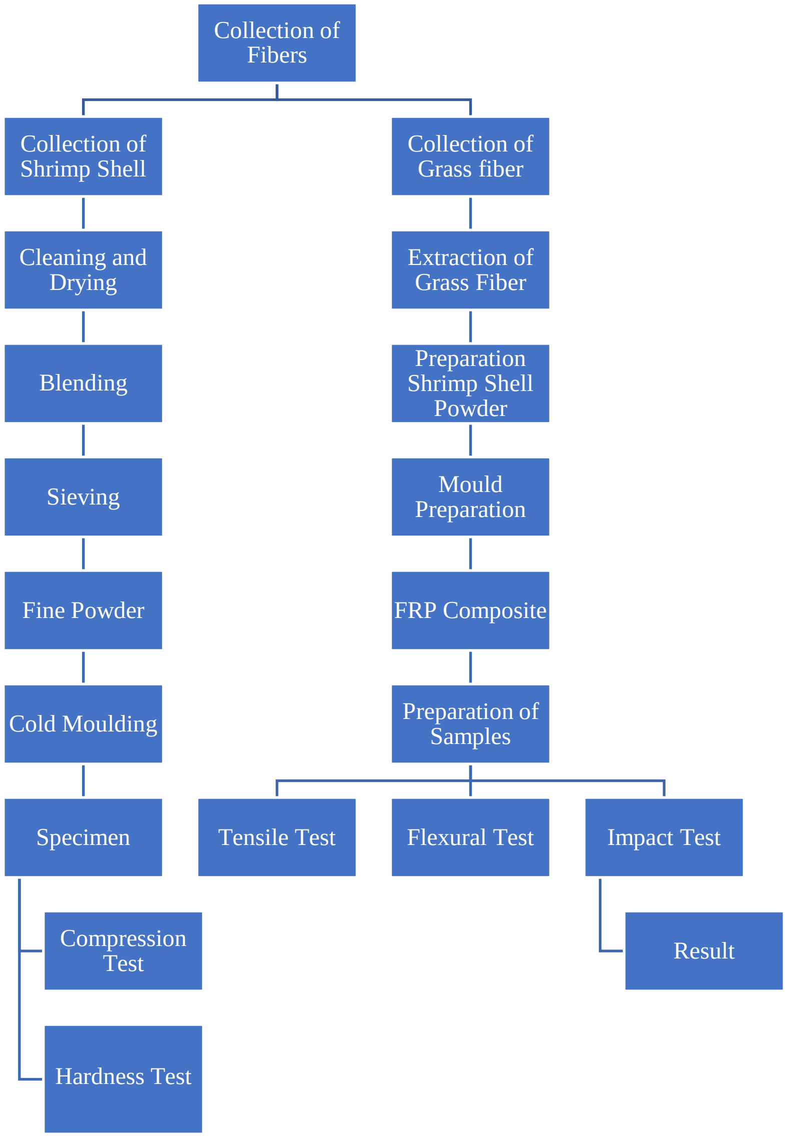

Figure 1. Process Flow chart.

Figure 2. a) Grass Fiber b) Shrimp shell collection c) Blending d) Sieving

The shrimp shell powder was then sieved to achieve a consistent particle size is shown in Figure 2(d). Epoxy resin and hardener were used as the matrix material for the composites [1]. The resin and hardener were mixed in a predetermined ratio as per the manufacturer's instructions to ensure optimal curing and bonding.

Composite Fabrication

The biodegradable composites were fabricated using the cold pressing machine which involves the following method:

Initially the fine shrimp shell powder loaded into the mold. After loading the mold is sealed to prevent pressure medium escape with a cap nut and the pressure is applied manually using a lever. After pressurization, the pressure is maintained for a specified time (110 seconds). When the holding time is completed then the pressure is released slowly using a lever and the densified cylindrical sample was unloaded. The cylindrical sample is shown in below Figure 3(b).

The biodegradable composites were fabricated using the hand layup method, which involves the following steps:

A rectangular mold surface was prepared using sheet metal and to prevent the polymer from sticking to the rectangular mold surface a solvent was applied [8]. The grass fibers were aligned in such a manner that the reinforcement would be strong. Now, the Resin and Hardener were taken in a measuring jar. Resin and hardener were mixed thoroughly after that the fine Shrimp shell powder was added to the constitute and then mixed properly in a suitable ratio. This mixed polymer was poured into the rectangular mold distributed uniformly all over the rectangular mold surface as shown in Figure 3(c). A roller was used to acquire uniform structure and to prevent the air bubble settled in the polymer. This process was repeated until required size composite was obtained [11,15]. Weights are placed on the composite and the composite let to dry for 48 hours. The composite was removed carefully from the rectangular mold and the final FRP composite was given for cutting according to ASTM models as shown in Figure 3(d)&(e). The total process is shown as a flow chart in Figure 1.

MECHANICAL TESTING

The mechanical properties of the fabricated composites were evaluated using standardized testing methods:

For Cylindrical Sample

The compressive strength of the composite was determined through UTM. Prepared specimens in a cylindrical shape as shown in Figure 4 (a) and the compressive load was applied until failure. The hardness of the composites was determined through the Rockwell hardness test (ASTM D785). A standardized indenter was pushed into the surface of the composite, and the hardness value was recorded.

Figure 3. a) Cold Pressing Machine b) Unloading the Cylindrical Sample c) Hand Lay Up Process d) Final FRP Composite e) Cutting according to ASTM models.

Figure 4. a) Compression Test Sample b) Hardness Test Sample.

For Fiber Reinforced Polymer (FRP) Composite:

In accordance with ASTM D638 guidelines, a universal testing machine (UTM) was used to assess the composites' tensile strength [6, 12, 13]. As shown in Figure 5, samples were made in the shape of a dog bone. The breaking point was reached by applying a tensile stress. Strength was assessed using the ASTM D790 three-point bending test, and the maximum load and elongation at break were measured. As shown in Figure 6, rectangular samples were applied to the center until they failed after being loaded with support [14]. The specimen's dimensions and the load at failure were used to calculate the flexural strength [7].

The impact resistance of the composites was evaluated using the Charpy impact test method (ASTM D256). Notched specimens were shown in Figure 7 were subjected to a swinging pendulum, and the energy absorbed during fracture was measured and recorded [9,10].

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RESULTS

The load versus displacement behavior of the cylindrical sample under compression is presented in Figure 8.

Table 1. Compression Test for Cylindrical Sample.

Maximum Force (Fm)kN	21.480
Displacement at maximum load mm	9.42
Maximum Displacement mm	9.73
Compressive Strength MPa	30.267

Figure 5. Tensile Test Sample.

Figure 6. Flexural Test Sample.

Figure 7. Impact Test Sample.

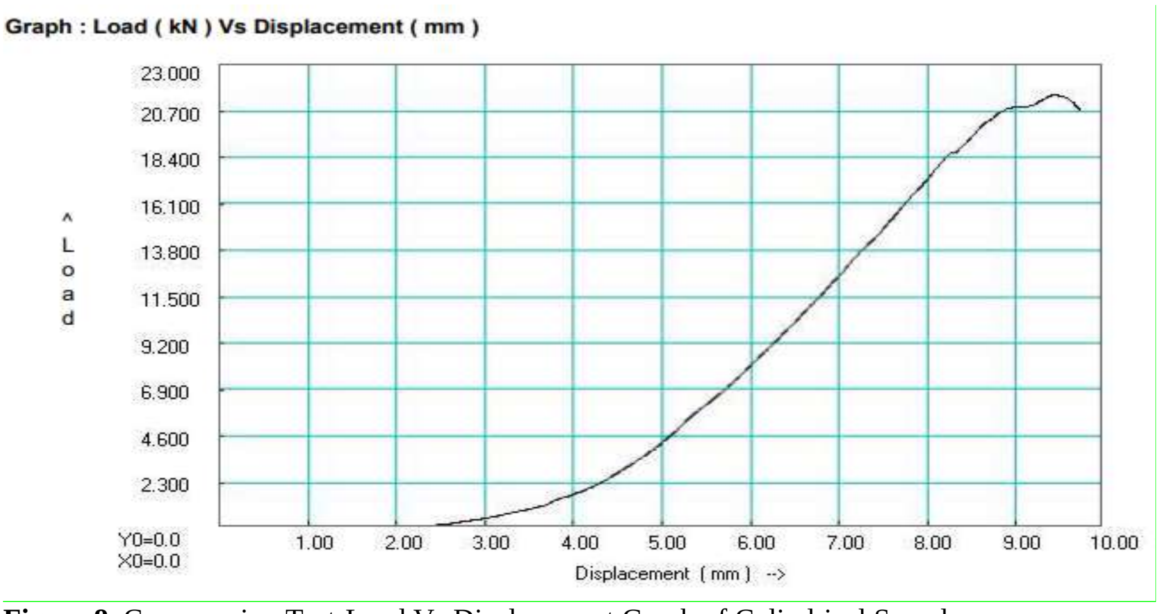

Figure 8. Compression Test-Load Vs Displacement Graph of Cylindrical Sample.

Figure 9 and Table 2 summarize the Shore D hardness measurements taken at three different points on the cylindrical sample. The observed values ranged from 13 to 17, indicating the consistency in surface hardness across the sample.

Table 2. Shore D Hardnes for cylindrical sample.

Point	Shore D Hardness
1	13
2	15
3	17

Table 3. Tensile Test for GFSPRP.

Maximum Force (Fm)kN	1.480
Displacement at maximum load mm	2.10
Maximum Displacement mm	2.20
Tensile Strength (Rm) MPa	27.684
Elongation %	2.20

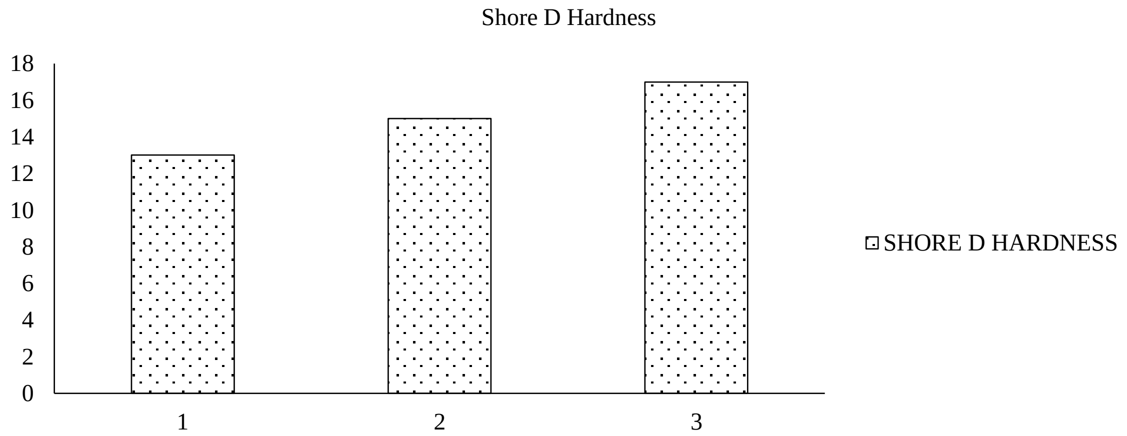

Figure 9. Shore D Hardness Test Graph for Cylindrical Sample.

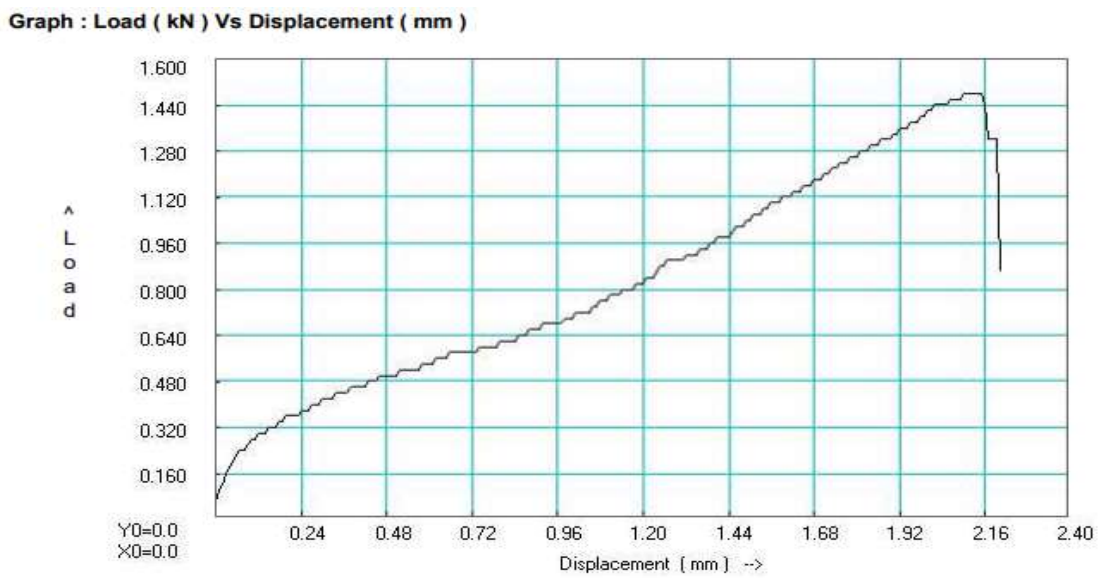

Figure 10. Tensile Test-Load Vs Displacement Graph for GFSPRP.

The load versus displacement response during tensile loading of the grass Fiber shrimp powder Reinforced Polymer (GFSPRP) composite is illustrated in Figure 10. The mechanical properties derived from Table 3 are as follows:

Young's modulus (E) calculation for GFSPRP Composite
E = stress/strain
Stress = load / area = 1440/100 = 14.4 N/mm^2
Strain = change in length / original length = 3.62/160 = 0.022
Therefore, E = 14.4/0.022 = 654.54 N/mm^2.

Table 4 presents the results from the three-point bending test performed on the shrimp shell composite (GFSPRP) sample. The specimen, with a width of 19.53 mm, thickness of 4.73 mm, and span length of 80 mm, withstood a force of 40 N.

As shown in Figure 11, the GFSPRP sample after impact testing had an impact strength of 4.20 kJ/m², highlighting its energy absorption capacity under sudden loading conditions.

DISCUSSIONS

The mechanical performance of the novel shrimp shell powder-based biodegradable composite has been investigated through systematic experimental testing and has been benchmarked against both conventional synthetic and natural fiber composites.

For the cylindrical specimen (Figure 8), the compression test revealed a compressive strength of 30.267MPa withstanding up to 21.480kN of load and a maximum displacement of 9.73mm (Table 1). These results highlight the material's capability to resist compressive forces, supporting its applicability for load-bearing biodegradable structural components. Further, Shore D hardness values for the same specimen ranged from 13 to 17 (Table 2, Figure 9), indicating moderate surface hardness. Such a profile suggests a material balance between toughness and flexibility, enabling its use in scenarios that require both structural strength and resilience.

In the grass Fiber shrimp powder Reinforced Polymer (GFSPRP) composite configuration, tensile tests resulted in a strength of 27.684MPa at a maximum load of 1.480kN and an elongation of 2.20% (Table 3). The stress-strain curve (Figure 10) demonstrated elastic behaviour up to peak load, with a calculated Young's modulus of 654.54N/mm². These results establish that the FRP composite maintains mechanical integrity when subjected to tensile loading. In addition, the material exhibited a flexural strength of 10.99MPa under a 40N bending force (Table 4) and an impact resistance of 4.20KJ/m². Collectively, these values indicate the composite offers a well-rounded suite of mechanical properties suitable for applications requiring moderate load-bearing and impact resistance.

Table 4. Flexural Test for GFSPRP

S. No	Sample Details	Width (mm)	Thickness (mm)	Span Length (mm)	Force (N)	Bending Strength (MPa)
1	Shrimp Shell Composite	19.53	4.73	80	40	10.99

Figure 11. Impact Test Sample After Testing for GFSPRP.

Comparison with conventional synthetic composites such as grass fiber shrimp powder reinforced polymers (GFSPRPs) shows that, while GFSPRPs possess higher tensile strengths (300–900MPa), they are non-biodegradable, require high energy inputs for processing, and present significant challenges in recycling [16]. By contrast, the shrimp shell-based composite, though exhibiting lower mechanical strength, provides marked advantages in terms of environmental sustainability and end-of-life degradability. This characteristic is especially pertinent for emerging applications in sustainable packaging, lightweight automotive assemblies, and biodegradable construction elements [17].

The developed composite also compares favourably with other natural fiber composites, including jute- and hemp-based materials [18]. The presence of chitin and calcium carbonate in shrimp shell powder enhances both durability and moisture resistance, conferring an advantage in humid or marine environments. This renders the composite suitable for eco-friendly marine applications, biodegradable automotive interiors, and temporary structural components in construction [19].

The shrimp shell powder-based composite offers a synergistic combination of moderate mechanical strength, durability, and superior environmental credentials, positioning it as an attractive alternative to synthetic composites for applications where sustainability and biodegradability are critical selection factors [20].

CONCLUSION

Based on these figures and reviewing the existing literature, shrimp shell powder may be used as fillers and grass as fibers in the composite material of FRP. We can reduce filling the land and dumping by using shell material to avoid pollution in the surroundings. Shrimp manufacturing will give more than 700,000 million tons wastes worldwide. The mechanical properties of fibers used in grass Fiber shrimp shell Reinforced Polymers (GFSPRP) demonstrate promising characteristics for various structural applications.

The compression test of the cylindrical sample developed by shrimp shell powder reveals that the material can withstand a stress of 30.267 MPa, indicating strong resistance to deformation under compressive loads. With a maximum load of 21.480 kN and a displacement of 9.73 mm, the fiber shows solid performance under compression, although it deforms significantly before failure. The Shore D hardness test shows moderate hardness values ranging from 13 to 17, suggesting that the material has a balance of resistance to indentation without being overly rigid or brittle, making it suitable for flexible yet durable applications.

In the tensile test, the fibre demonstrates a stress capacity of 27.684 MPa with a maximum load of 1.480 kN and an elongation of 2.20%, showing that it has moderate strength and limited flexibility. The Young's Modulus value of 654.54 N/mm² indicates that the material is relatively stiff and retains its shape well under applied forces. The flexure and impact strengths also show the good results.

The shrimp shell powder fillers with grass fiber exhibit a good combination of strength, moderate flexibility, and durability. These properties make them a potential material for use in sustainable and eco-friendly FRP composites in various engineering applications.

Future Scope of Work

Overall, the scope and future work for biodegradable grass fiber composites encompass advancing material development, optimizing processing techniques, exploring new applications, assessing environmental impacts, and striving towards enhanced performance and sustainability in material design and usage.

We can conduct a Metallurgical Properties; wear Test for the Grass fiber composite which could give us a better scope and knowledge about the composite.

The idea of using Shrimp Shell powder in the composite can be innovatively processed in future with a mixture of compositions.

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