

Development of Eco-friendly Glass Fiber Composites Embedded with Paddy Stubble for Sustainable Applications and Its Metallurgical Characterization

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Abstract

The extreme rise in environmental challenges owing to agricultural activities, among which paddy stubble burning remains a huge concern. Burning about 15 million tons of paddy stubble leads to emissions discharge of various toxic pollutants and gases notably, nitrogen oxides, methane and carbon monoxide in large scale causing global air pollution and climate change. The study focuses on obtaining and preparing a paddy stubble powder and using it with glass fibers and epoxy resin to make composite materials. The composites were prepared by the hand layup method and later their mechanical and metallurgical properties were studied through hardness tests, compression tests, microstructural assessments and water absorption tests. These biodegradable composite materials can be made from utilization of agricultural waste, reduction of environmental pollution through stubble burning and the provision of a substitute for conventional composite materials. The study implies the composite materials which are biodegradable are suitable for industrial purposes without posing environmental challenges there by supporting global efforts toward sustainability. Future directions for research include refining the composite mixtures and seeking other applications so as to improve the performance and environmental footprint of these materials.

Keywords: Biodegradable composite materials, Glass fibers, Paddy Stubble powder, Hand lay-up method, Sustainable materials, Environmental impact.

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INTRODUCTION

In recent years, the manufacturing industries is being put on sustainable development and this has encouraged research on the creation of recyclable products. Nonrenewable composite materials that are mostly used today contribute greatly to environmental degradation as a result of pollution and waste products. The use of biodegradable composites can be furthered as they make use of renewable resources and have lesser impacts on the environment. Rice straw is one of the many agricultural wastes created in morbidity of rice growing areas it is generated in millions of tons on an annual basis [1]. This rice straw is left in the fields and then the rice straw burned to clear the

land for the next crop. This practice has become common place. Such practices aggravate the air and degrade the soil and bring about the loss of precious organic materials which can be utilized elsewhere [2].

In India alone, 15 million tons of paddy stubble are abandoned and incinerated every year, causing atmospheric pollution by the discharges of substances. These emissions are even responsible for expanding the greenhouse effect and endangering the health of individuals living or working in such region. Refugees from and other environmental organizations surveyed placed loss of trees directly on countries and urban population at a serious risk for climate change [3]. The detrimental effects of stubble burning have led to quite a number of calls on what sustainable methods of waste management can be adapted. With this background this research study has set out to look into such possibilities through poundability of paddy stubble powder potential as a filler material in biodegradable glass fiber. To collect paddy stubble powder from agricultural waste and prepare it for use as a filler material in composite manufacture [6]. To develop biodegradable glass fiber reinforced composites employing the hand layup technique, adding paddy stubble powder in order to improve the mechanical properties [4]. To perform metallurgical analysis of the developed composites focusing on hardness, compression strength, microstructure and water absorption [5]. To examine the paddy stubble powder usage in composite materials for paddy stubble wastage reduction and paddy stubble waste sustainability [7].

The challenge of managing agricultural waste by converting paddy stubble into a valuable product and they can't burned into fields. Second, biocomposites development is in line with global strategies aimed at developing materials that are natural and will not last on land fills, thereby protecting the environment and also restoring soils quality. Finally, the results of this study may lead to the use of biodegradable composites for construction, automotive, consumer goods and other industries thereby promoting a circular economy.

LITERATURE REVIEW

The Composite materials and polymer matrix composite (PMCs) are become more popular due to they increased mechanical strengths and also they having light weight. Now a days there is an increasing trend using natural fibers such as jute, hemp and paddy stubble as reinforcement in composites as they are renewable and biodegradable. Paddy stubble is burned in large quantities in fields the environment is polluted [7-8]. The paddy stubble powder as filler material in composites provides a solution to this problem of waste disposal, and also enhances the tensile stress and impact strength of the composites. Studies reveal that although the composites are biodegradable, they can still be comparable with conventional materials and the use of those materials allows an environmentally friendly approach [1].

The type of filler and the ratio of filler have an effect on the mechanical capabilities of these composites. It has also been shown that the strength and hardness also increase on the introduction of paddy stubble, which can be utilized for different uses. The introduction of biodegradable materials also helps achieve environmental Objectives by reducing waste and improving ecofriendly practices. Finally to conclude the use of paddy stubble powder in biodegradable glass fiber composites is an effective way of formulating environmentally friendly composites [2].

METHODOLOGY

The methodology for this research was structured into several key phases, each phase dedicated to bringing about the successful preparation, fabrication and assessment of the biodegradable glass fiber composites is show in process flowchart Figure 1.

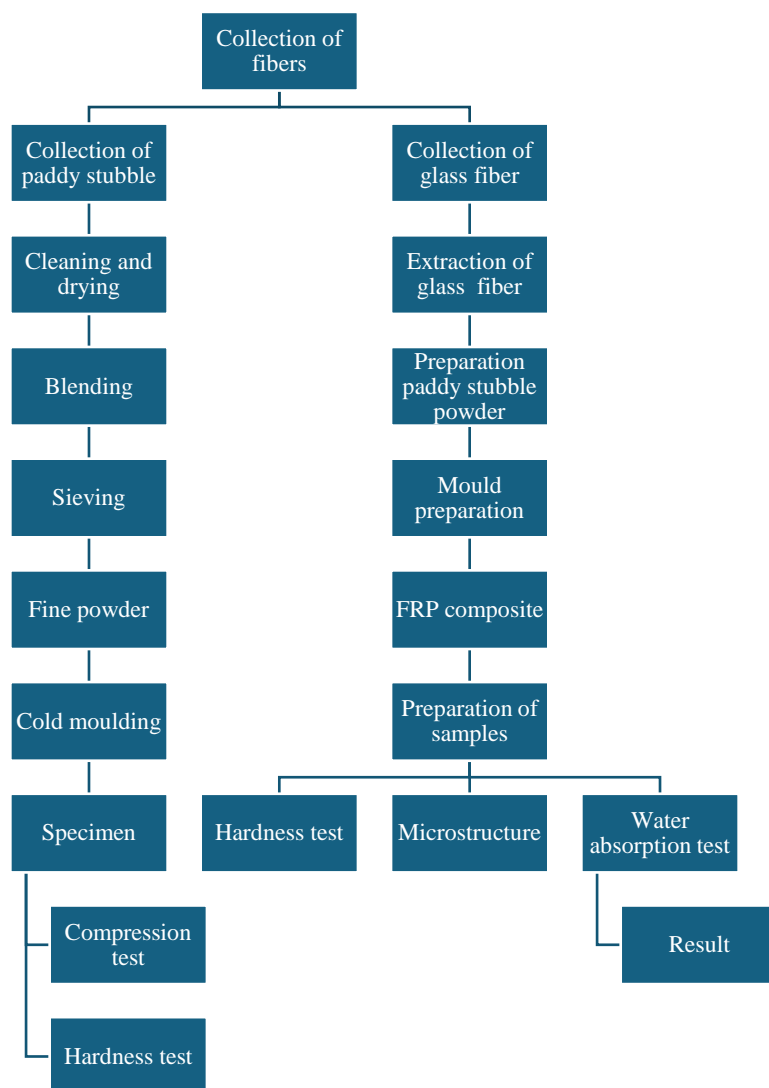


Figure 1. Process Flow Chart.

MATERIALS

Cold Moulding Of Cylindrical Samples

The Cylindrical Sample is prepared in the cold mold compression machining process as shown in Figure 2 (a) & (b). In this process the stubble powder as shown in Figure 2 (b) is placed into the cylindrical mold and some liquid is adding to it then compress the powder into certain pressure the mold prepared in cylindrical shape as shown in Figure 2 (c) & (d)

The cylindrical stubble powder samples are used for compression and hardness test to check the stability of the powder, which was used as a filler material in composites.

Composite Fabrication

Regarding research of paddy stubble, such a raw material was used for production of biodegradable composites which was harvested during the favorable time of the agricultural season. The stubble was cut into small pieces. The chopped paddy stubble was exposed to air to bring down the amount of moisture content. Dried stubble was placed in a grinder to crush and break the stubble into powder as shown in Figure 3 (b). A measuring device was then used to sieve and sift the broken stubble into powdered form to control the size of stubble particles for uniformity in the composite as shown in Figure 3 (a) & (b).

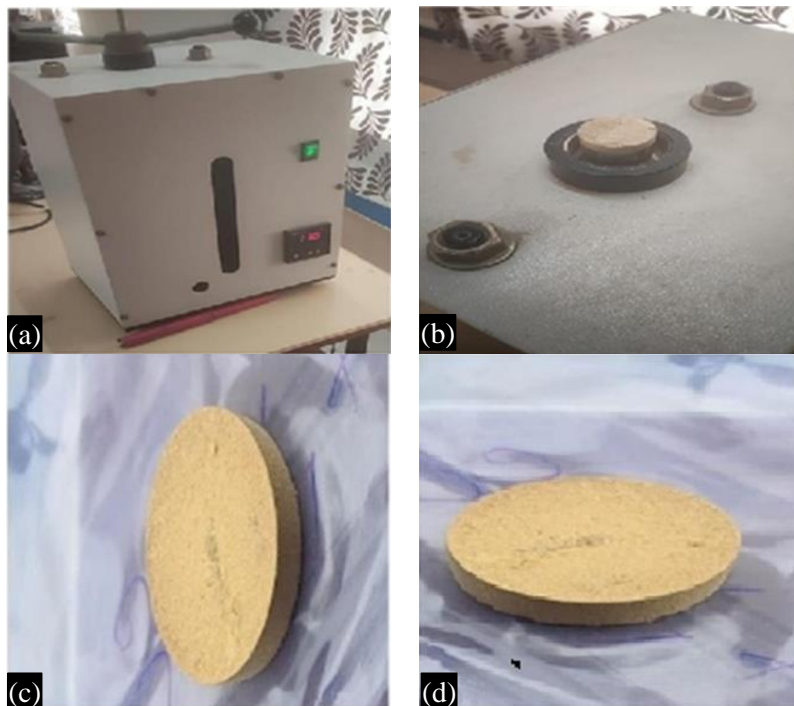


Figure 2. (a) Cold Mould Machine (b) Cylindrical Mould (c) Hardness Test Specimens (d) Hardness Test Specimens.

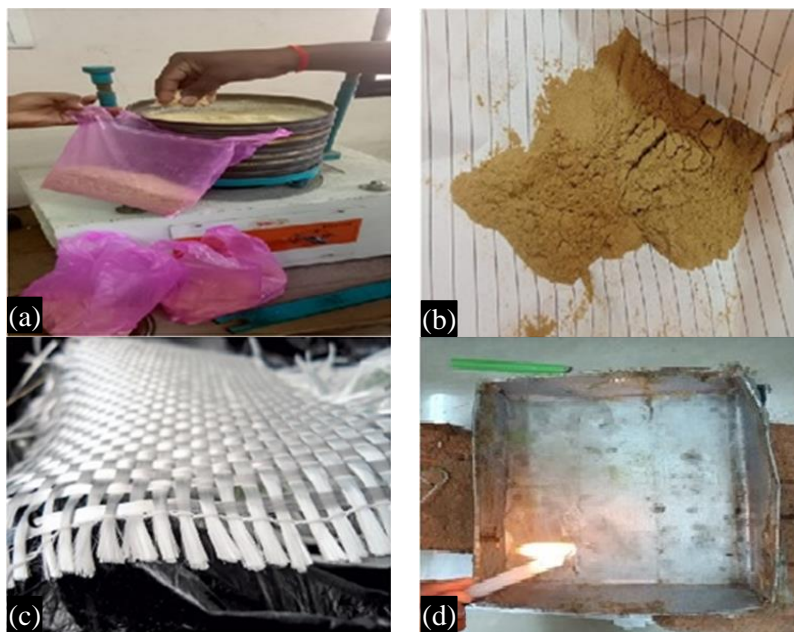


Figure 3. (a) Sieving Process, (b) Stubble Powder, (c) Glass Fiber, (d) Hand Layup Process.

Hand Layup Method

The composite was made by using hand layup. The mold was prepared to form the composite. The release agent was applied to the mold so that the composite would easily come out after curing process. The resin and hardener are mixed and stubble powder is stirred in the resin as filler material. Then the epoxy resin is applied on the surface of the mould. The glass fiber put over the resin coated mould in the linear direction as shown in Figure 3(c). The procedure was repeated to form several layers so that, the fiber would be saturated with the resin. The epoxy resin is applied at the top of the composite and weight is placed and left over at room temperature for drying.

Metallurgical Testing

The hardness of materials, especially about composites, is usually assessed through the use of Shore D hardness test. The Shore D Durometer ASTM D2240 or ISO 868, which is used for measuring the hardness of materials is shown in Figure 4 [11]. Microscopic studies have been carried out using optical microscope to study the filler material the sample is shown in Figure 5 (a) [12].



Figure 4. Hardness Sample.



Figure 5. (a) Microscopic Sample, (b) Water absorption test.

For water absorption test, Composite samples are submerged in water at any specified period the least commonly used time is 24 hours to 48 hours as shown in Figure 5(b). Note the initial and final weights of samples are determined to calculate percentages absorbed.

The Compression testing and hardness test is done for specimens prepared in the form of cylinders of dimensions using paddy stubble powder as shown in in Figure 2 (c) & (d). UTM is used for compression test and shore D hardness is used for hardness [11].

RESULTS AND DISCUSSIONS

Compression & Hardness Test for Cold Forming of Cylindrical Mould Using Paddy Stubble

The results of the experimental tests on biodegradable glass fiber composites reinforced with paddy stubble powder yield information regarding the metallurgical properties of this material. General findings from hardness and compression tests highlight the performance of stubble powder which was cold moulded in a cylindrical form gives the stability of the stubble powder which was used in composite preparation as a filler material.

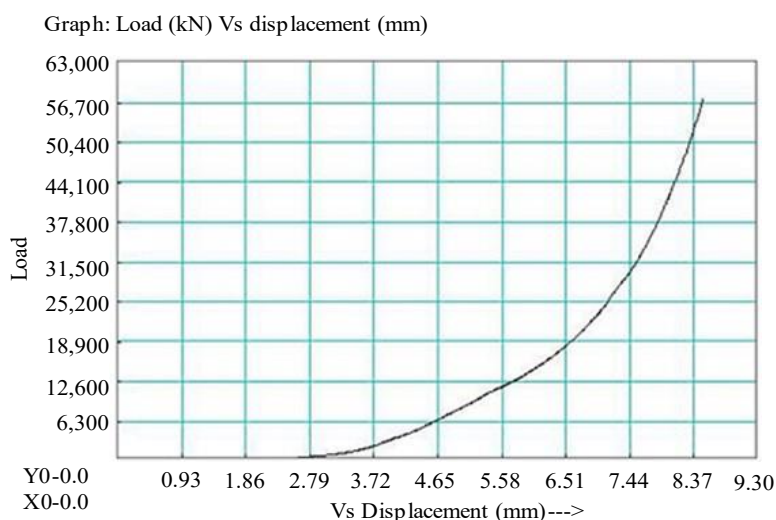


Figure 6. Compression strength graph for cylindrical mould.

Table 1. Results for Compression Test.

Maximum Force (Fmax)	57.400 KN
Disp. at Max load	8.51 mm
Max Displacement	8.51 mm
Compressive Strength	80.666 MPa

Table 2. Results for Compression Test in terms of points and hardness

Points	Shore D Hardness
1	46
2	48
3	47

**Figure 7.** Shore D Hardness for cylindrical mould.

The Figure 7 shows the shore-D hardness for the cylindrical mould, the results ranged from 46 to 48 for the first two points and at the third point it is 47. Figure 6 show the compressive strength graph and the Table 1 and 2 shows the values which were obtained from UTM. The sample shown in Figure 2 (c) & (d) had a compression strength of 4.27 MPa which implies that axial loading can be substantially applied on the composite. This quality is essential for application in materials that carry load [6]. It can be assumed that the composite has satisfactory performance when subjected to compressive loads in a number of structural applications, especially those that would favor low weight biodegradable composite materials as per the literature. Adding paddy stubble powder as a filler material increases not only the metallurgical properties of the composite but also helps eliminate agri waste problems [9]. This method helps control air pollution. The composite being biodegradable also suits green initiatives that allow it to break down and enhance soil without adding to land fill waste [13].

Hardness Test Rectangular Composite Sample

In Figure 8 and Table 3 shows Shore D hardness testing results ranged from 66 to 68 for the first two points, with the third point at 62 according to the distance. A medium to high hardness level exists in both points. The shift from first point to second point with so little improvement in hardness test scores means additional stubble powder indented more of the material. It is the percentage of stubble powder concentration with respect to the hardness expansion at the second point that causes abnormal indentation hardness to improve further. The water absorption of the composite sample is 8.82% after 48 hours.

Table 3 Results for Hardness.

Distance (mm)	Shore d hardness
20	62
70	66
120	68



Figure 8. The Shore D-hardness graph for rectangular sample.

Water Absorption

Calculation of water absorption percentage using
 Water Absorption (%) = $[(m_1 - m_0)/m_0] \times 100$
 where m_0 = initial dry weight, m_1 = weight after water absorption
 $m_0=3.4$, $m_1=3.7$

Water Absorption (%) = $[(3.7 - 3.4)/3.4] \times 100$
 Water Absorption (%) = 8.82%

Microstructure of Composite

The microstructure in Figure 9 shows the stubble powder as a filler material is mixed with resin and hardener in proper mixing ratio. The glass fibers also aligned in linear direction and form a layer's intern form a composite material is shown in microscopic view. The stubble powder reinforcement is done uniformly is also shown in Figure 9. As per the literature the stubble powder reinforcement with glass fibers had shown a good results [14].

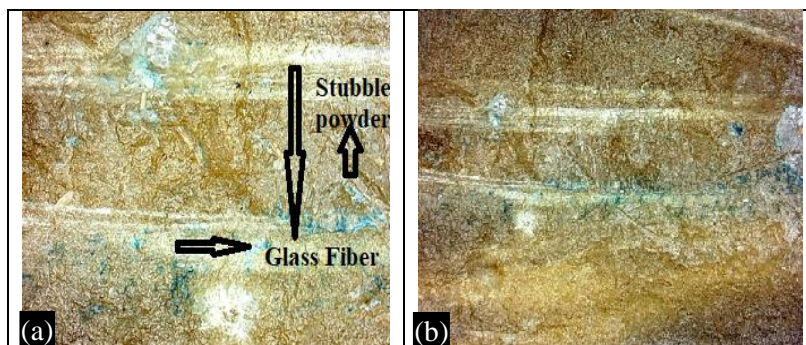


Figure 9. Microstructure for Composite

CONCLUSION

The experimental tests on biodegradable glass fiber composites reinforced with paddy stubble powder demonstrate promising metallurgical properties. The cold forming of the paddy stubble powder shows the stability with their hardness and compressive strength value. The Shore-D hardness tests show moderate to high hardness values, indicating the composite's ability to withstand indentation, with results ranging from 62 to 68 depending on the stubble powder concentration. The compressive strength of 4.27 MPa confirms that the composite can endure significant axial loading, making it suitable for structural applications requiring low-weight, biodegradable materials. The addition of paddy stubble powder enhances the metallurgical properties of the composite while addressing agricultural waste, contributing to environmental sustainability. Moreover, the biodegradable nature of the material supports green initiatives by reducing landfill waste and enhancing soil quality. The water absorption of 8.82% after 48 hours suggests that the composite has moderate moisture resistance. Microstructural analysis reveals the proper dispersion of stubble powder, resin, hardener, and aligned glass fibers, further supporting the composite's structural integrity. Overall, the use of paddy stubble powder in biodegradable composites provides a viable solution for both improving material performance and promoting sustainable practices in composite material production.

Future Potential

The overall scope of future work on biodegradable glass fiber composites is the advancement of material development, optimized processing techniques, new potential applications, assessments on environmental effects, and continued pursuit to improve performance with sustainability considerations in material design and application. We can run a wear test for glass fiber composite [10]. In the future, the composite can be innovatively processed by a mixture of compositions in order to use Paddy Stubble Powder.

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