BIO-BASED COMPOSITES FROM WASTE AGRICULTURAL RESIDUES: MECHANICAL AND MORPHOLOGICAL PROPERTIES

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This investigation aims to study the potential of waste agricultural residues, such as rice husk and coir pith particulates, as reinforcement in epoxy matrix as an alternative to wood and plastic based components. The composites were prepared using the compression molding technique by varying the particulate weight content from 10 to 50%. The tensile test, flexural test and impact test were performed to study the mechanical properties of the prepared composites and the morphological study in fractured specimens was carried out using Scanning Electron Microscopy (SEM). The addition of rice husk and coir pith particulates to reinforce the epoxy composite has considerably increased the mechanical properties of the composites. This investigation suggested the possibility of introducing hybrid bio-particulates obtained from waste agricultural residues in polymer matrix composites.

Keywords: coir pith, epoxy, mechanical testing, rice husk, SEM

INTRODUCTION

Due to environment and sustainability issues, this last decade has witnessed remarkable achievements in green technology, particularly in the field of materials science through the development of bio-composites. Among possible alternatives like wood and plastic based materials, the development of bio-composites using waste agricultural residues (including stalks of most cereal crops, rice husks, and coconut fibers) is currently a matter of attention.[1,2] Most of the developing countries are very rich in agricultural fiber production and a large part of agricultural waste is being used as fuel. India produces more than 400 million tons of agricultural waste, such as bagasse, maize cobs, peanut shells and other wastes.[3] Agricultural residues are excellent potential alternative waste materials to substitute plastic products, due to their availability. Apart from their abundance and renewability, the utilization of agricultural residues is advantageous to the economy, environment, and technology, due to their low density, low manufacturing energy demand, low CO_2 emission, and high level of biodegradability, when compared to thermoplastic polymer composites reinforced by inorganic fillers.[4-6] The effective utilization of corn straw, soy stalk, wheat straw and other fibers with biodegradable resin enhances the strength of the agricultural residues.[7,8] Recent research in the use agricultural fibers as reinforcement in composites has witnessed the possibility of hybrid particulate reinforced composites.[9-11] The current investigation is focused on the development of an epoxy composite reinforced by coir pith and rice husk hybrid particulates to produce customer value-added products, due to the attractive physical and mechanical properties of bio-particulates.

EXPERIMENTAL

Materials

Waste agricultural residue particulates, namely coir pith and rice husk, were collected from coir mounds and rice industry, respectively, from the southern region of Tamilnadu, India. Coir pith was sun dried for 2 days, subsequently larger particulates were removed by hand sorting and uniform particle size was achieved using 50 µm sieves. The rice husk of 50 µm size was dried using an air dryer oven at 100 °C for 2 h. The epoxy resin matrix material (LY556) was obtained from Jeevitha Traders, Chennai, India. The density of epoxy resin at room temperature is 1.20 g/cm^3. The HY951 graded hardener of 0.98 g/cm^3 density was used to gain a homogeneous mixture of the resin system.

Preparation of bio-composite

A stainless steel mould with the size of 300 × 300 × 3 mm^3 was used for composite fabrication. Wax was used as a releasing agent and the epoxy was mixed with hardener in the ratio of 10:1. The coir pith and rice husk were mixed with the epoxy resin by varying the percentage of particulate weight content (10-50%) and blended by simple mechanical stirring at 20 rpm for 10 min at room temperature (25 °C). The mixture was poured into the mould in the compression molding machine at the temperature of 80 °C and the pressure of 2.6 MPa was maintained for 3 h so as to get uniform curing of the composite sheets.

Mechanical testing and morphological study

The tensile and flexural tests were conducted using a Universal Testing Machine (Model No.: UNITEK 94108) with a cross head speed of 5 mm/min, and the impact test was performed using a pendulum type Tinius Olsen Izod impact test apparatus. The specimens were tested for tensile, flexural and impact strengths, as per ASTM D638, ASTM D790 and ASTM D256, respectively. Five specimens were tested for each set of conditions and average values of tensile, flexural and impact strength were reported. Studies on the morphological properties of the fractured composites were carried out using a HITACHI Scanning Electron Microscope (SEM). After mechanical tests, the fracture surfaces of the specimens were sputter-coated with gold before analysis in order to eliminate electron charging.

RESULTS AND DISCUSSION

Tensile strength of bio-particulate composites

The evaluated tensile strength values of bio-particulate reinforced epoxy composites are shown in Figure 1. The unreinforced epoxy was tested and a tensile strength of 10 MPa was recorded. The addition of particulate content created a better reinforcing effect in composites and a maximum tensile strength of 13 MPa was observed for composites with 40 wt% of coir pith particles. The highest tensile strength value of 18 MPa was achieved with rice husk-epoxy combinations (30:70), which is 27.7% higher than that of the coir pith-epoxy composites. The low value of tensile strength for coir pith-epoxy composites is due to the weak bonding and low compatibility between the particulate and polymer matrix.[11,12] The reason for the higher value of tensile strength in rice husk composites may be the crystalline structure of rice husk, which enriches the load carrying capacity of the composites. The addition of rice husk particles in coir pith-epoxy composites improved the tensile strength (15 MPa) of the hybrid composites. The tensile strength of the hybrid composite increased with the increase of particulate weight content and the maximum value was observed for the composite reinforced with 30% weight content of particles.

Flexural strength of bio-particulate composites

The unreinforced epoxy was tested and a flexural strength of 15 MPa was recorded. Figure 2 shows the flexural strength of bio-particulate reinforced epoxy composites. The plot shows a linear increment in flexural strength values up to a certain level of particulate loading and then a gradual drop caused by a higher proportion of particulates in the composites. The coir pith-epoxy composites exhibited the maximum flexural strength of 23 MPa at 30% particulate content. The flexural strength of the composites was further improved by impregnating rice husk particulates, along with the coir pith particles. The flexural strength of hybrid composites was observed to be maximum (37.9 MPa) for the addition of 20% rice husk and 20% coir pith particles into the epoxy matrix. The presence of silica in the rice husk increased the stiffness of the composites, which was evidenced by the maximum value of flexural strength compared with the tensile strength value.

Impact strength of bio-particulate composites

Figure 3 shows the effect of particulate content on the impact strength of bio-particulate reinforced epoxy composites. The unreinforced epoxy was tested and an impact strength value of 2 J was recorded. The coir pith-epoxy composites exhibited the impact energy of 2.9 J at 30% coir pith weight content, whereas the rice husk-epoxy bio-composite exhibited the maximum impact energy of 3.3 J at 40% rice husk content. The hybrid bio-particles reinforced epoxy composite exhibited the maximum impact energy of 3.9 J at 15% rice husk and 15% coir pith reinforcement. The interaction between agricultural residues and the epoxy matrix played a major role in improving the impact strength of the composite. The obtained results indicated that the bio-particle reinforced hybrid composite gained a gradual improvement in impact strength.

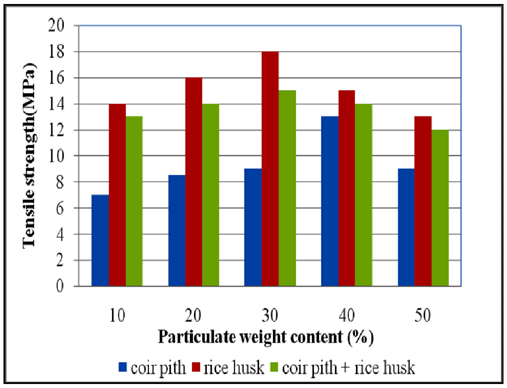

Figure 1: Effect of particulate content on tensile strength of bio-composites

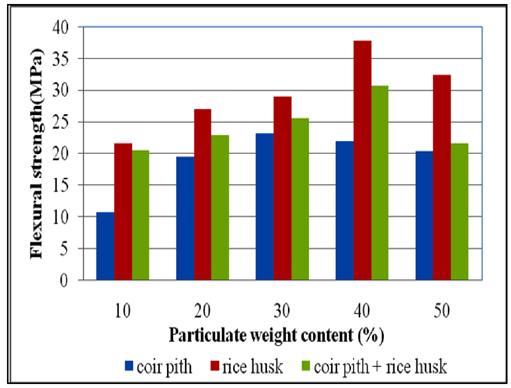

Figure 2: Effect of particulate content on flexural strength of bio-composites

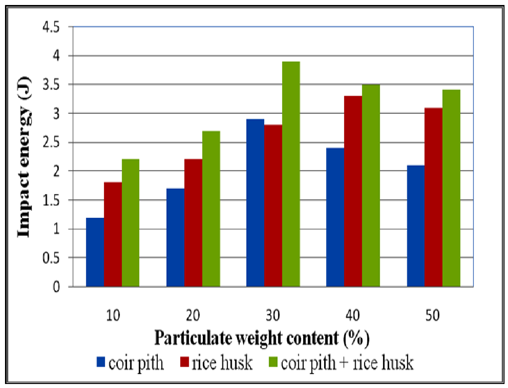

Figure 3: Effect of particulate content on impact strength of bio-composites

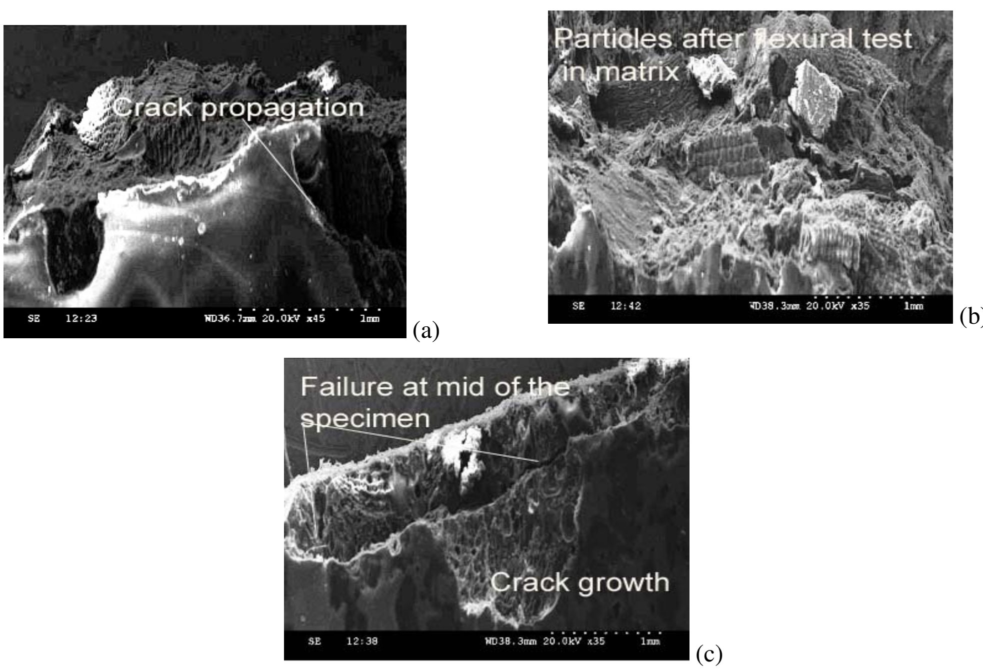

Figure 4: SEM images of fracture surfaces after (a) tensile, (b) flexural and (c) impact testing

SEM analysis of fractured surfaces

The interfacial adhesion between the particulates and the matrix was examined using SEM, as shown in Figure 4. The tensile fractured specimen showed uniform crack propagation due to better mixing of the particulates and the matrix. Particulate segregation was found to be good in the fractured region, which might be due to the improvement in compatibility between the waste residue particulates and the resin matrix (Figure 4a). The SEM image of the specimen after flexural testing shows regular disruption of particles over the matrix system (Figure 4b). The disruption of particles in the matrix confirms their participation in restricting the flexural load against bending.[13] The fractured region of the specimen after impact testing reveals a strong bonding between ligno-cellulosic particulates and the epoxy matrix (Figure 4c). The distribution of particles also helped in arresting the crack growth near the failure region of the composites.

CONCLUSION

From the experimental results, it was found that the average tensile, flexural and impact strength values for coir pith and rice husk hybrid bio-particle reinforced epoxy composite were 12.7 MPa, 24.3 MPa and 2.6 J, respectively. The mechanical performance of the coir pith-epoxy composite was improved by incorporating rice husk particulates. The hybrid composite with coir pith and rice husk particulates may open up new applications for low load bearing needs. However, as may be concluded from the results presented in this study, significant improvements in strength and fracture characteristics must be realized for this class of materials.

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