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Tensile and Water Absorbing Properties of Natural Fibre Reinforced Plastic Composites from Waste Polystyrene and Rice Husk

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Abstract: *This paper presents a study on the development of Natural fibre reinforced plastic composite from the waste polystyrene and rice husk, a new class of composites consisting of polystyrene based resin reinforced with rice husk fibre. Four different sets of polystyrene/rice husk composites were fabricated with addition of 10, 20, 30 and 40 wt% of rice husk particulates. Tensile and water absorbing properties of these composites were evaluated as per ASTM standard. Tests for water absorption were performed by immersing the samples in a bath of distilled water at room temperature and water uptake was measured gravimetrically along the process. It was observed that young modulus, force at peak, percentage water absorbed and diffusion coefficient of the composite increased while elongation at peak force decreased with addition of rice husk in the PBR matrix. The highest values of young modulus, force at peak, diffusion coefficients and elongation at peak force at 40 % rice husk content are: 365 N/mm^2, 562 N, 1.77E-04 mm^2/s and 0.76 % respectively. The recycled rice husk in combination with the PBR has produced plastic composite with moderate tensile and water absorbing properties applicable in various application.*

Keywords: *Plastic Composite, Rice husk waste, Polystyrene Based Resin, Polystyrene Waste.*

1 INTRODUCTION

The incessant need of global environmental security has brought natural fibres reinforced polymer composites into the competing stance over synthetic composites. Their preferred advantages include: high strength to weight ratio, high strength at elevated temperatures, high creep resistances and high toughness. These advantages can also be in the form of their light weight, high durability and design flexibility. One of the applicable natural fibres is rice husk fibres (Mallick, 2007).

The production of natural fibre composites involves the use of either a thermoset or thermoplastic polymer matrix/binder system combined with a natural fibre component. Polyester, Epoxy and phenolic resin are the regularly used thermoset matrix whereas polypropylenes, polyethylene, polystyrene and elastomers occupy the large-scale position in thermoplastic matrix. In automotive applications, the most common polymer used today is thermoplastic polypropylene, particularly for non-structural components. (Holbery and Houston, 2006). Moreover, rice husks as fillers have advantages over mineral fillers since they are non-abrasive, require less energy for processing and have ability to reduce the density of furnished products (Hardinnawirda and SitiRabiatull, 2012).

Several works on the application of rice husk as the reinforcing agent in plastic composites have been reported. Atuanya *et al.* (2013) investigated the effect of rice husk filler loading on the mechanical properties of recycled low-density polyethylene (RPE) mixed with a fraction of virgin polyethylene (MPE) composites it was observed that tensile strength increased up to 10 percent weight fraction of rice husk filler in the composites and later decreased above 10 percent filler loading. Tensile modulus, flexural strength and modulus, and Brinell hardness increased with increasing filler loading, but impact strength decreases with increase in filler loading.

Dimzoski *et al.* (2009) studied properties of rice-husk-filled polypropylene (PP) composites. Using the concept of linear elastic fracture mechanics, introduction of rice husks in the PP matrix resulted in a decreased stress at peak, together with increase of composites tensile modulus and modulus in flexure. Painter & Coleman (2008) investigated the increase of the rice husk as natural filler in the PP matrix and found out that the tensile modulus and water absorption of the composite were improved.

Productions of composite often involve huge investment in material acquisition. One way of reducing the production cost but still maintaining the properties of the composite is by using natural filler such as rice husks from the waste stream and also a synthesised matrix from the waste stream. Rice husks have been chosen due their availability, low cost, low density, high specific strength and modulus, and recyclability (Rahman *et al.*, 2015).

In the current work, the effect of rice husk as a filler in polystyrene matrix composites had been studied. The solvated polystyrene-based resin (PBR) from a waste thermoplastic source is the matrix material. The synthesised solvated PBR is a non-epoxy resin with classic advantages like good adhesion to other materials, good mechanical properties, good environmental and chemical resistances (Abdulkareem and Adeniyi, 2017).

2 MATERIALS AND METHODS

2.1 Materials

In the development of the plastic composite using Rice husks and polystyrene resin, the materials were sourced from municipal solid waste. The Rice husks were gathered from Shonga farm in Edu local government, Ilorin and were sieved to 150 µm size, while, the Styrofoam used was basically gotten from solid wastes streams of the University of Ilorin.

2.2 Preparation of rice husks

The rice husks gathered were dried in oven for 24 hours at 50^o C to remove free water present in it. The dried sample was graded to obtain the particle size of 150µm.

2.3 Preparation of Rice Husk Filled Polystyrene Composite

The synthetic polystyrene-based resin (PBR) was produced from the dissolution of waste Styrofoam in a chosen solvent as reported in Abdulkareem *et al.*, 2017. The Rice Husks (RH) particles of 150µm in size were mixed with PBR in a mixer by simple mechanical stirring. The mixing of PBR and the graded RH was done thoroughly to enable uniform composition at any point for each of the composite scheduled in Table 1. The mixture was further pressed using a single roller on the metal plate. After mixing, the material was placed on a flat surface and further compacted with the aid of a single roller. Oil was smeared on the metal surface to prevent the polymer from sticking and to achieve easy composites removal after curing. The spread composite was then made to cure under ambient conditions for 7 days.

Table 1: Composition of the Composites

Composites	Compositions
C1	100% matrix + 0% Rice Husks
C2	90% matrix + 10% Rice Husks
C3	80% matrix + 20% Rice Husks
C4	70% matrix + 30% Rice Husks
C5	60% matrix + 40% Rice Husks

2.4 Mechanical Testing

The tensile tests were conducted using a Universal Testing Machine (UTM: M500-50) at room temperature, according to the ASTM D638-10 Standard. The loading rate applied to measure the bond strength was controlled at 4 mm/min. It was fitted with load cell and extensometer to record the test load and elongation accurately. Tensile loads were applied till the failure of the sample and load-elongation curves was obtained for all the composite materials produced. Three specimens were used for all the tests and final results represent the average.

2.5 Water Absorption and Diffusion Coefficients

Water absorption of the samples of composites were determined according to the ASTM standard method (D1037-99, ASTM, 1999). The rectangular samples of 15.4 cm x 4.6 cm were soaked in water at room temperature (20-22 ^{o}C) for 10 days. Composites samples 20 X20X4 mm^3 were cut-off from composites developed, and their edges were sealed with PBR prior to water absorption testing and dried in an oven at 50 ^{o}C for 24 hours.

The water absorption experiments were carried out according to the following procedures. Firstly, the pre-dried composites samples were immersed fully into a water baths kept at room temperature. In regular intervals of process, the samples were removed from the water bath and wiped with tissue paper to remove surface water and immediately water uptake was measured gravimetrically by using an electronic balance (uncertainty l 0.001 g). Following, the samples composites were immersed in the water bath again to continue the sorption process until the equilibrium condition was reached. Each measure procedure of the absorbed water was done in less than 1 min, so, water evaporation at the surface was insignificant. The results of absorbed moisture were presented as mass of absorbed water by dry composites mass. The moisture content was computed using Equation (1).

$$M\ (t) = \frac{W_t - W_o}{W_o} \times 100\% \qquad (1)$$

where W_0 and W_t represent the dry weight of the composites samples (t = 0) and the wet weight at any specific time t, respectively.

The diffusion coefficient, Dx, was calculated for each composite developed using equation 2 (Shen and Springer, 1976).

$$D_x = \pi \left[\frac{h}{4M_m}\right]^2 \left(\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}}\right)^2 \qquad (2)$$

where *'Mm'* is the maximum percentage of moisture content, *'h'* is the sample thickness, *'t_1'* and *'t_2'* are the selected points in the initial linear portion of the plot of moisture absorption (*Mt*) versus immersion time t and *'M_1'* and *'M_2'* are the respective moisture content.

3 RESULTS AND DISCUSSION

3.1 The Influence of Rice Husk Fibres on the Mechanical Properties of the Composite

Effects of rice husk fibre incorporation with polystyrene on the Young's modulus, force at peak and elongation at peak force are presented in Figures 1, 2 and 3.

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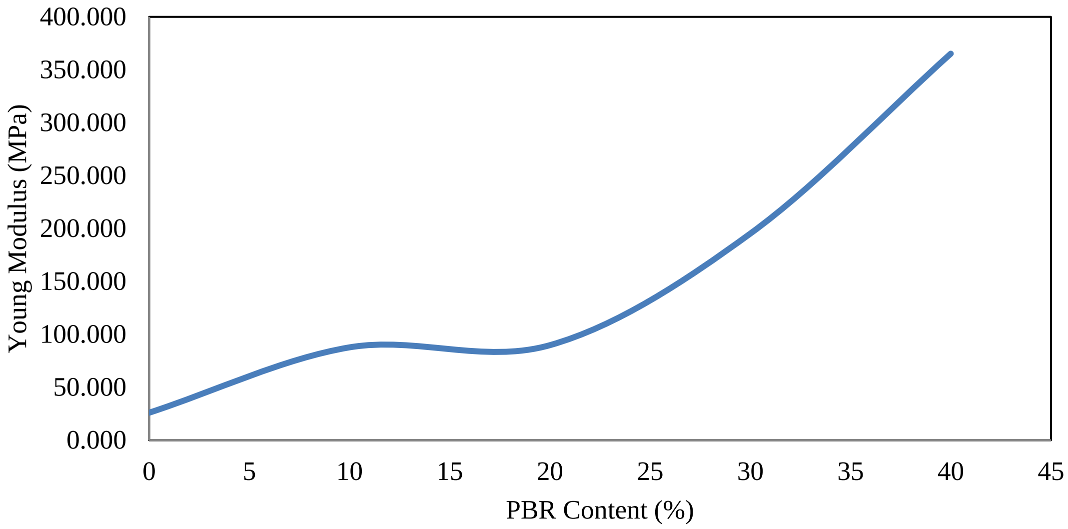


Figure 1: Effect of rice husk fibre incorporation with polystyrene on the Young's modulus

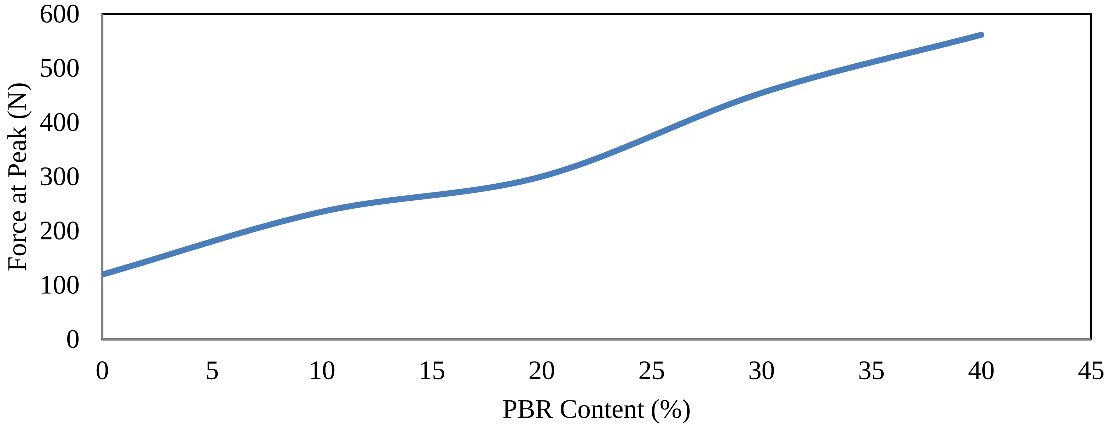


Figure 2: Force at peak of the resultant Polystyrene / rice husk composites

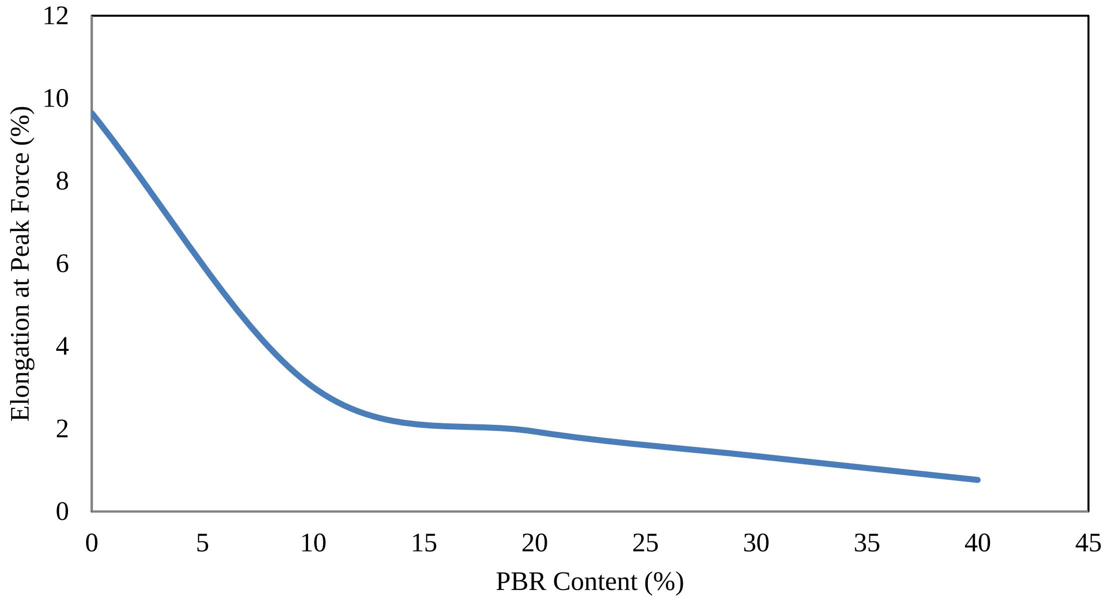


Figure 3: Elongation at break of the resultant Polystyrene / rice husk composites

Young's modulus is frequently used as a marker to evaluate the rigidity of polymeric materials and is used as such here. The effect of rice husk fibre incorporation with polystyrene on the Young's modulus, force at peak and elongation at break of the resultant Polystyrene / rice husk composites are summarized in Figures 1, 2 and 3, respectively. The young modulus of polystyrene / rice husk composites increased progressively with increasing rice husk fibre content up to 40% w/w, at which point the resultant composite young modulus was 365 MPa as against the 2.5 – 7 MPa range of pure Polystyrene (BASF, 2016). Evidently, rice husk fibre incorporation into polystyrene via PBR matrix had significantly affected the Young Modulus of the Polystyrene / rice husk composite, it is concluded that rice husk presented interfacial adhesion with polystyrene and could add into the PBR matrix and reinforce the strength of the polystyrene / rice husk composite.

3.2 Force at Peak and elongation at break

The elongation at break is an indicator for determining the toughness of the composite developed. The elongation at break calculated for polystyrene/rice husk composites was less than 10% at 0% fibre loading and less than 1.5 % at 40% fibre loading. For polystyrene/rice husk composites with increasing filler loadings (0%–40%) (Figure 2). Polystyrene are ductile in nature while rice husk exhibit brittle behaviour. Thus, the gradual increase in brittle behaviour is due to the incorporation of the reinforcement material and may arise from inter-structural progression in which filler particles are dispersed in the inter-aggregate space (Joseph *et al.*, 2002).

At low filler loading, the matrix is not adequately reinforced. So, it could not withstand high load, and eventually failure happens at higher elongation. However, at higher filler loading, the matrix is increasingly reinforced and endures high load before the breaking point is reached. Therefore, the force at peak and elongation at break are inversely related. The reinforcement mechanism preludes that, at higher filler loading, the molecular mobility drops because of the formation of physical bonds among rice husk particles. (Nwanonenyi and Obidegwu, 2012**;** Islam *et al.*, 2009**).**

3.3 Water Absorption of Polystyrene/ Rice Husk Composites

The influence of rice husk content on the water absorption of Polystyrene/ rice husk composites is summarized in Figures 4.

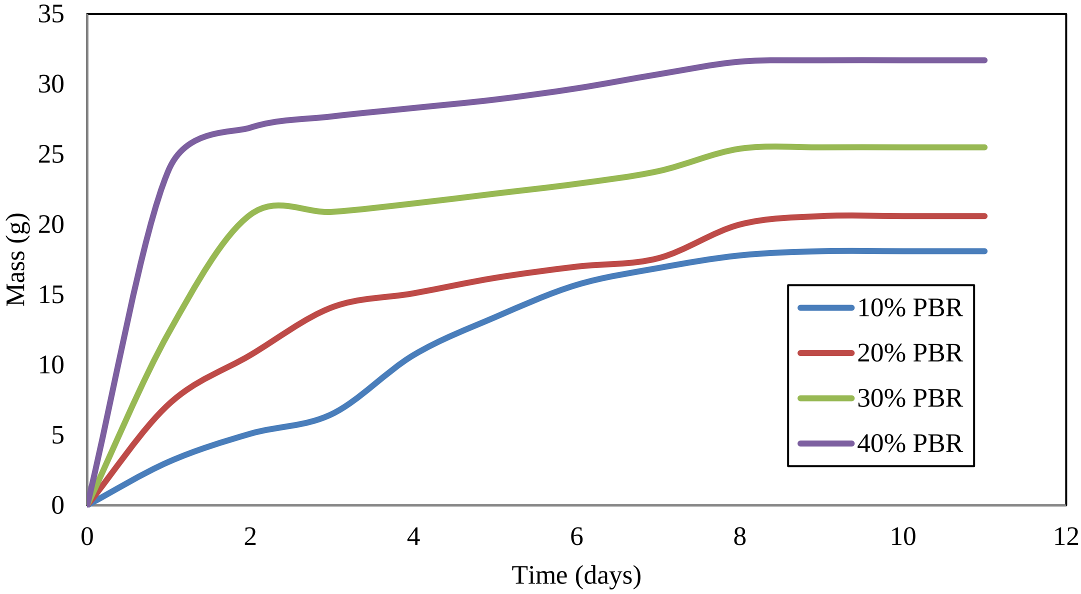


Figure 4: Influence of rice husk content on the water absorption of Polystyrene/ rice husk composites

The water absorption of both polystyrene / rice husk composites increased continuously day by day until it became steady at 10th day. Normally, polystyrene do not have good water absorption. Rice husk was not considered as a hydrophilic material, but the significantly increased water absorption of both polystyrene / rice husk composites were likely to be attributed to the many pores and gaps in the rice husk structure. This makes the rate of water absorption to increase with increase amount of rice husk fibres, this is in agreement with Wang *et al* (2005).

3.4 Diffusion Coefficients

The influence of rice husk content on the moisture diffusion rate in Polystyrene/ rice husk composites is presented in Table 2.

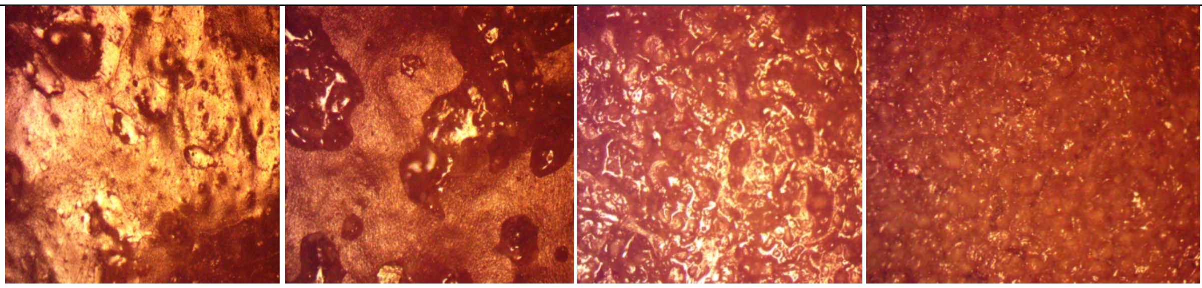
Table 2: Diffusion coefficients of water in rice husk filled polystyrene composites

Rice Husk Content (%)	Diffusion Coefficient (mm^2/s)
10	2.78822E-05
20	6.62305E-05
30	1.62E-04
40	1.77E-04

The diffusion coefficient or diffusivity (Dx) of moisture absorption is the measurement of speed of diffusion. It characterises the ability of solvent molecules to move among the polymer segments Joseph *et al.*, 2002. From equation 2, values of Dx were evaluated for each composite developed and summarized in Table 2. The values of diffusion coefficient were found in the range of 2.8×10^{-5} to 1.8×10^{-4} mm^2/sec which is in conformity with the work of Wang *et al* 2005 with HDPE-Rice Husk composite. The rate diffusion was smallest with the composite of 10% RH with higher plastic content which indicated smaller velocity of diffusion in interfacial gap between fibre and the PBR matrix (Ana *et al.*, 2004). However, the rate of diffusion increased as the percentage of RH increase in the PBR matrix. This could be possible due to lower plastic content in the composite that could accelerate the diffusion in these cases. In other words, the diffusion coefficient increases with RH fibre loading (Cao *et al.*, 2006; Wang *et al.*, 2006)

3.5 Microstructure Analysis

Figures 5a, b, c and d show the optical micrographs of 10, 20, 30 and 40 % RH reinforced polystyrene composites respectively.



a b c d

Figure 5: Photomicrographs of polystyrene composites at 10 % (a), 20 % (b), 30 % (c), and 40 % Rice Husk Reinforcement

Micrographs reveal that there is a unform distribution of RH particulates at higher percentages of RH in PBR matrixes. Furthermore, it can be seen from the optical micrographs, that there is good dispersion of reinforcement in the matrix and the reinforcement particulates resulting in better load transfer from the matrix to reinforcement material as evident in the analysis of mechanical properties discussed.

Moreover, RH particles are dispersed in the PBR matrix and do not interact with each other properly at the lower RH content, as can be observed from the optical photomicrographs of these composite materials (Figures 5 a and b). For particle content greater than 20 % (Figures 5 c and d), interparticle distance is smaller, causing a large increase in the effective diffusivity of the composite, in the range of high percentage RH content, the particles touch each other and form agglomerates and chain, as shown in the optical photomicrographs and hence higher absorption of water molecules.

4 CONCLUSIONS

This research work aimed at determining the mechanical and moisture transport properties of plastic composite samples formulated and produced from waste rice husks and polystyrene. This has been successfully achieved. The following conclusions can be drawn from the work:

(i) that the young moduli for rice husk reinforced polystyrene composites are greatly influenced by the percentage of reinforcements present in the composite.

(ii) The incorporation of filler material brings about an increase in the rate of water absorption, in other words, diffusion coefficient increases with increase in percentage of RH fibres in PBR matrix.

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