IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 10, Issue 1, January 2020, ||Series -VI|| PP 06-16

Preparation and Properties of Rice Husk Fiber Based Polystyrene Composites from Wastes Streams

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Received 03 January 2020; Accepted 17 January 2020

I. INTRODUCTION

1.0 Background to the Study

Composites are the material of two or more distinct components on macro scale with different properties to form a new material with a property that is entirely different from the individual constituents. The primary phase of a composite material is called a matrix having a continuous character. In other words, matrix is a material which acts as a binder and holds the fibers in the desired position thereby transferring the external load to reinforcement. These matrixes are considered to be less hard and more ductile. The composite material consists of a matrix along with a fiber with some filler material. The reinforced material can be either synthetic or natural fibers. (Bentur *et al*., 2006).

To meet the continous demand of increasing environmental security, several natural fibers reinforced polymer composites (NFPCs) are brought into the competitive market. They provide a wide range of advantages over synthetic fiber based composites. These advantages include high strength to weight ratio, high strength at elevated temperatures, high creep resistances and high toughness (Sethy, 2011). These advantages can also be in the form of their light weight, high durability and design flexibility. One of them is rice husk fibres.

In NFPCs, the used matrices are either thermoset or thermoplastic. Polyester, Epoxy and phenolic resin are the commonly used thermoset matrix whereas polypropylenes, polyethylene and elastomers occupy the large scale position in thermoplastic matrix. Based on the matrix used, composite material can be divided into three types i.e. Metal Matrix Composite (MMC), Polymer Matrix Composite (PMC) and Ceramic Matrix Composite (CMC). The selection of any of the above composite material depends upon the type of application. The most commonly used composites are polymer matrix composite. (Gupta and Kumar, 2014).

The manufacture of natural fiber composites includes the use of either a thermoset or thermoplastic polymer binder system combined with a natural fiber preform or mat. In automotive applications, the most common system used today is thermoplastic polypropylene, particularly for nonstructural components. Polystyrene is favoured due to its low density, excellent processability, mechanical properties, and good dimensional stability and impact strength (George *et al*., 2001). Other than that, 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. Hence, these composites have attracted much attention, and are becoming increasingly important for the production of a wide variety of cheap lightweight environment friendly composites. (Hardinnawirda and SitiRabiatull, 2012).

In the present study, the polystyrene based resin (PBR) from a thermoplastic source is the matrix material. PBR is a non-epoxy resin with classic advantages like good adhesion to other materials, good mechanical properties, good environmental and chemical resistances etc (Abdulkareem and Adeniyi, 2017).

1.1`Problem Statement

Productions of composite often involve huge investment in material acquisition.One way of reducing the production cost but still maintaining the properties of thecomposite is by using natural filler such as rice husks from the waste stream and also a sythesised matrix from the waste stream. Rice husks had been choosen duetheir availability, low cost, low density, high specific strength and modulus, andrecyclability (Ismail *et al*., 2001; Ndazi 2001). In the current work, the effect of ricehusk as a filler in polystyrene matrix composites had been studied.

1.2Aim

The aim of this project is to produce Rice Husk Fiber Based Polystyrene Composites from Wastes Streams and test for some of its physical and mechanical properties.

1.3Objectives

(i) To determine the effect of different percentage of filler in polystyrene matrix material using rice husks.
(ii) To evaluate the mechanical and physical properties of polystyrene matrix material using rice husks.

1.4 Scopes

The scopes of this project include:
(i) Preparation of rice husks
(ii) Preparation of rice husks- polystyrene resin composites with different filler loading
(iii) Several tests such as (a), and (b) had been carried out in order to determine the properties of the composites.
(a) Tensile Test (ASTM D3039)
(b) Water Absorption Test (ASTM D570)

1.4 Justification of Study

Polystyrene (Styrofaom) is beneficial and convenient for many uses. But, the downside is its poor impact strenght which is due to the stiffness of the polymer backbone i.e. it is brittle. It also has a low tensile strength relative to other thermoplastics.

The other limitations of polystyrene are poor UV and oxygen resistance, and it can be attacked by hydrocarbon solvents.

Due to these reasons, polystyrene composites are produced and different filler materials are incorporated to these composites to make it more viable and to enhance its properties.

Rice husk was selected due its non-abrasive structure, require less energy for processing and have ability to reduce the density of furnished products.

These composite can be used as a basis for the production of many products like plastics, adhesives, varnishes, toys, containers, automotive parts, home appliances, medical applications etc.

II. LITERATURE REVIEW

2.1 Composite

Composites can be defined as combinations of two materials one of which is called the reinforcing phase which can be in the form of fiber sheets or particles and are embedded in the other material called the matrix phase. The objective is to take benefit of the superior properties of both the materials without compromising on the weakness of either. Mechanical properties of composites depend on the size, shape and volume fraction of the reinforcement, reaction at the interface matrix material (Wang, 1998).

The composites are compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their short comings, in order to obtain improved materials (Nucleus, 1996). There are two categories of constituent materials of composite materials: matrix and reinforcement. The matrix material supports and surrounds the reinforcement materials and simultaneously maintains there relative position. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties (Matthews *et al.*, 1999).

2.1.1 Matrix Phase

1. The primary phase, having a continuous character.
2. Usually more ductile and less hard phase.
3. Holds the reinforcing phase and shares a load with it.

2.1.2 Reinforcing Phase

1. Second phase (or phases) is embedded in the matrix in a discontinuous form,
2. It is sometimes called reinforcement phase as it is usually stronger than matrix phase.

2.1.3 Types of Composites:

Broadly composites are classified on the basis of the two main phases present in them that is matrix phase and reinforcing phase as follows:

On the basis of Matrix Phase:

1. Metal Matrix Composites (MMC)

Metal Matrix Composites are composed of a metallic matrix (aluminum, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase. Metal Matrix Composites have many advantages over monolithic metals like higher specific strength, higher specific modulus and better properties at higher temperatures, and at lower thermal expansion coefficient (Yeomans, 2008).

2. Ceramic Matrix Composites (CMC)

Ceramic Matrix Composites are composed of a ceramic matrix and reinforced with short fibers, or whiskers such as those made from silicon carbide and boron nitride. Ceramic fibers, such as alumina and SiC (Silicon Carbide) are advantageous in very high temperature applications, and also where there is a risk of environment attack (Rhodes *et al.,* 1988)

3. Polymer Matrix Composites (PMC)

Polymer Matrix Composites are composed of a matrix from thermosetting (Unsaturated polyester (UP), Epoxy) or thermoplastic (PVC, Nylon, Polystyrene) and embedded glass, carbon, steel or Kevlar fibers (dispersed phase). Most commonly used matrix materials are polymeric. Processing of polymer matrix composites need not involve high pressure and doesn't require high temperature. Also equipment required for manufacturing polymer matrix composites are simpler (Chawla and Krishan, 2012).

On the basis of reinforcing material:

a) Fiber Reinforced composite

Common fiber reinforced composites are composed of fibers and a matrix. The reinforcement phase consists of fiber and the main source of strength while matrix glues all the fibers together in shape and transfers stresses between the reinforcing fibers. The fibers carry the loads along their longitudinal directions. Common fiber reinforcing agents include carbon graphite fibers, asbestos, beryllium, beryllium oxide, molybdenum, aluminum oxide, bio fibers glass fibers, polyamide etc. Similarly generally used matrix materials include epoxy, polypropylene, phenolic resin, vinyl ester, polyester, polyurethane, etc. Polyester is most widely used among these resin materials. (Chandramohan and Marimuthu, 2011).

b) Particle Reinforced composite

Particulate Composites consist of a matrix reinforced by a dispersed phase in form of Particles. Particles used for reinforcing include ceramics and glasses such as small metal particles such as aluminum and amorphous materials, mineral particles, including carbon black and polymers. By using particles modules of the matrix gets increased and ductility of the matrix gets reduced. Particles are also used to reduce the cost of the composites. An example of particle reinforced composites is an automobile tire, which has carbon black particles in a matrix of poly-isobutylene elastomeric polymer. (Chandramohan and Marimuthu, 2011).

2.1.4 Natural Fiber Composite

Since recent past, environmental apprehension encourages the researchers from every part of the world on the studies of natural fiber composite and cost effective option to synthetic fiber reinforced composites. The ease of manufacturing and availability of natural fibers have tempted researchers to try locally available inexpensive natural fibers and to study their expediency of reinforcement purposes and to what extent they satisfy the required

specifications of good reinforced polymer composite for different applications. With high specific mechanical properties and low cost, natural fiber represents a biodegradable and good renewable alternative to the most common synthetic reinforcement, i.e. glass fiber. Increased technical innovation, continuing political and environmental pressure, identification of new applications and government investments in new methods for fiber harvesting and processing are leading to projections of continued growth in the use of natural fibers in composites, with expectation of reaching 100,000 tons per annum by 2010 (Clemons *et al.,* 2005).

When the specific modulus of natural fibers is considered, the natural fibers show values that are comparable to or even better than glass fibers. Material cost savings, due to the use of natural fibers and high fiber filling levels, coupled with the advantage of being non-abrasive to the mixing and molding equipment make natural fibers an exciting prospect. These benefits mean natural fibers could be used in many applications, including automotive, building, household appliances, and other applications. Composites in which the matrix phase is some natural fiber while the reinforcement phase may be thermoplastic material or any other like epoxy, polypropylene etc. is called Natural Fiber Composite. Since last decade, polymer composites reinforced with natural fibers have become a topic of concern due to desirable properties and broader applications of natural fibers. Also, natural fibers are very cheap, abundantly available, and renewable. So the products based on natural fiber composite having reinforced phase as thermoplastic material are more economical to produce than the original thermoplastics (Maldas *et al.,* 1988).

The application of composite materials in engineering as dielectric is becoming increasingly important. Therefore, studies on the electrical properties of natural fiber reinforced thermoplastic composites are very important (Augustine and Thomasz, 1997). Natural fiber composite materials have gained importance and popularity due to their lightweight, high stiffness, strength, corrosion resistance, and lower impact on the environment. Because of their quality, durability and other advantages, they are used to make a large variety of floor mats, yarn, rope etc. Plants, such as jute, sisal, kenaf, pineapple, flax, cotton, hemp, ramie, bamboo, banana, etc., as well as wood, a source of lignocellulose fibers, are usually applied as the reinforcement of composites. Their renewability, availability, low density, and price as well as overall good mechanical properties make them an attractive ecological alternative to glass, carbon and synthetic fibers used for the manufacturing of composites. Some natural fiber composites are: Bast fibers (flax, hemp, jute, kenaf…)-wood core surrounded by stem containing cellulose filaments, Leaf fibers (sisal, banana, palm), Seed fibers (cotton, coconut coir). Generally, plant or vegetable fibers are used to reinforce polymer matrices of natural fiber composites and plant fibers are a renewable resource and have the ability to be recycled which gives an extra edge over synthetic fibers (Mallick and Pankar, 2007).

Advantages

1. Available in plenty
2. Cheap
3. Renewable
4. Corrosion resistance
5. Light-weight and Good strength

2.2 Rice Husk Plastic Composites

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) and mixed with a fraction of virgin polyethylene (MPE) composites it was observed that tensile strength increased up to 10 percentweight 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 increases with increased filler loading, but impact strength decreases with increased in filler loading. (Nwanonenyi and Obidegwu, 2012) analysed the Mechanical Properties of Low Density Polyethylene/Rice-Husk Composite using Micro Mathematical Model Equations and the result showed that there is a distinct variation between the experiment results and results from micro mathematical model equations, the mechanical properties of the composite indicate that it may be useful in some applications that require low strength, high stiffness and hardness

(Nwanonenyi and Ohanuzue, 2011) in another research investigated on the Effect of Rice-Husk Filler on Some Mechanical and End-Use Properties of Low Density Polyethylene where the Results showed that tensile modulus and hardness increased with increase in filler loading, while tensile strength and % elongation decreased with increase in filler loading. In addition, it was also observed that end-use properties such as water absorption, specific gravity and flame retardant properties increased as filler loading increases. (Dimzoski *et al.,* 2009) studied properties of rice-hull-filled polypropylene (PP) composites. Using the concept of linear elastic fracture mechanics, Introduction of rice hulls in the PP matrix resulted in a decreased stress at peak, together with increase of composites tensile modulus and modulus in flexure. Patricio Toro et al 2006 investigated the increase of the ricehusk charge as natural filler in the PP matrix decreases the stiffness, and in the presence of PP-g-MMI as compatibilizer in PP/rice-husk, the tensile modulus and water absorption of

the composite were improved.

(Rosa *et al.,* 2009) studied on the Properties of Rice-Husk-Filled-Polypropylene composites with Maleic anhydride modified propylene as the coupling agent, it was verified that tensile strength decreased with filler loading. The presence of MAPP improved this property showing a strong dependence on the MAPP/RHF ratio

(Choi *et al.*,2006)developed a new recycling method for rice husks and waste expanded polystyrene, with a view of using the styrene solution of waste expanded polystyrene as a binder for rice husk-plastic composites, their water absorption and expansion in thickness are decreased with increasing binder content and filler-binder ratio, since the composites formed have a high flexural strength and water resistance, their uses as building materials are expected.

(Shivappa *et al.,* 2013) carried out a research on rice husk reinforced with vinylester polymer composite, though the work showed a lot of fluctuation on the tensile and flexural strength of the composites, it increased but not steady (Vasanta *et al.,* 2013) used rice husk as an additional fiber with coir fiber to reinforce vinyl ester from observations, there were improvement in mechanical properties of the composite material formed (both in tensile and flexural strength)

From the works reported, it was observed that polyethylene reinforced with rice husk exhibited increase in tensile modulus, flexural strength and hardness during the loading of the filler but tensile and impact strength dropped at the early stages of the loading, then for the polystyrene and polypropylene their tensile modulus, flexural strength increased but showed improvement when a compatibilizer was used on polypropylene composite. Polyethylene composites has higher elongation at break more than other polymer composites, that is why rice husk exhibited more useful mechanical properties in its composites both in recycled form, also the tensile strength of rice husk composites increased when used as an additional fiber to coir in reinforcing vinyl ester, showing that they are gradually substituting synthetic fibers and the tensile strength of the composites is not falling.

2.3 Rice Husk Composite Production Method

The rice husk fibers were separated from undesirable foreign materials (matter) and pith and then ground with hand grinding machine. The ground rice husk was then sieved to get very smooth fine textured particles. Then the composite was formed by integrating selected rice husk with a matrix. [Daniel *et al.,* 2003] The mixture of reinforcement/resin does not really become a composite material until the last phase of the fabrication, that is, when the matrix is hardened [Daniel *et al.,* 2003] The characteristic of composites depends on the nature of the reinforcement, the ratio of resin to reinforcement, and the mode of fabrication, so the basic methods applicable to rice husk composite fabrication include: extrusion process, injection moulding and compression moulding, the extrusion process is preferable to other methods due to its ability to create very complex cross-sections and to work on brittle materials. (Daniel *et al.,* 2003) (Oberg *et al.,* 2000)

2.4 Problems and Challenges Facing Biocomposites

This effort to develop biocomposite materials with improved performance for global applications is an ongoing process, it has been proved that it has low density, easily affordable, biodegradable, renewable and environmentally friendly it is faced with a whole lot of problems like Low impact strength (high concentration of fiber defects), Problem of stocking raw material for extended time, UVresistance– not better than plastics, Fiber degradation during processing and Fiber orientation and distribution. (Balaji, 2015)

(Nwanonenyi and Obidegwu, 2012) in their research showed that tensile strength and percentage elongation of the composite exhibited a gradual decrease with increase in filler loading while tensile modulus and hardness showed gradual improvement with increase in filler loading. The mechanical strength of a biocomposite could not match that of synthetic composites and the natural fibers would not replace synthetic fibers in all applications. For the last decades, extensive research is ongoing in order to improve the mechanical properties of biocomposites, while the intrinsic properties of the natural fibers such asbiodegradability and low specific gravity of the fibers remainunchanged. (Begum and Islam, 2013)

III. MATERIALS AND METHODS

In the development of the conductive composite using Rice husks and polystyrene resin, the materials were sourced for appropriately; the equipment was also properly checked before operation. The required procedures were then carried out progressively.

3.1 Materials

1. Rice husk: The Rice husks were gathered from Shonga farm in Edu local government, Ilorin and were sieved to 150 μm size.

Fig 3.1: Rice husks gathered from Shonga farm

2. Styrofoam: The Styrofoam used was basically gotten from solid wastes streams of the University.

Fig 3.2: Styrofoam waste from solid waste stream

3) Petroleum Solvent: The solvent used was petroleum based.

3.2 Equipment

1) Weighing balance: The weighing balance was used to get accurate measurement of materials used during formulation. It was also used to measure samples.

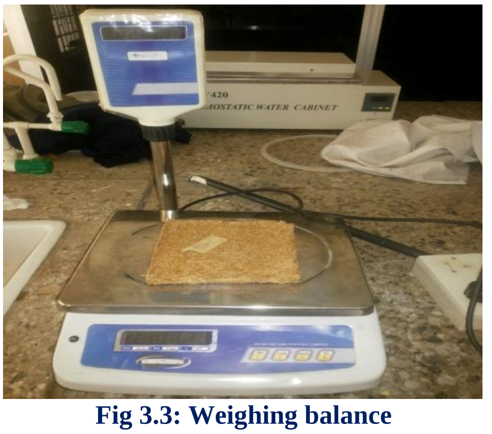

Fig 3.3: Weighing balance

5) Set of sieves: This was used to obtain the required size for the rice husk fiber (25µm)

Fig. 3.4: Set of sieves

Other equipment used was; Stirrer, bowls, venier caliper, meter rule and roller.

3.3 Methods

3.3.1 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 25µm.

3.3.2 Preparation of Polystyrene resin

The synthetic PBR was produced from the dissolution of waste Styrofoam in a chosen solvent. 59g of EPS was dissolved in 100ml of the solvent to obtain 145ml resin weighing 124g empirically. The density of the resultant resin was 855kg/m^3 upon re-solidifying at room temperature within 48 hours when left uncovered. No effort was made to evaluate the viscosity of the synthetic resin; and the amount and type of volatile organic compounds (VOC) released during the synthesis.

3.3.3 MixingofRice Husksand Resin

The Rice Husks of 25µm in size were mixed with Styrofoam based resin in a mixer by simple mechanical stirring. The mixing of the two materials was done thoroughly to enable uniform composition at any point. The mixture further pressed using a single roller on the metal plate.

Table 3.1 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

3.3.4 Spreading andCompacting

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.

3.3.5 Maturing and Finishing

The spread composite was then made to cure under ambient conditions for 7 days

3.4. Mechanical Testing

The tensile and flexural tests were conducted using a Universal Testing Machine (UTM) at room temperature, according to the ABNT NBR 14810:2006 Standard16. The loading rate applied to measure the bond strength was controlled at 4 mm/min. Modulus of rupture (MOR) and Modulus of elasticity (MOE) were determined by three-point bending test in the Universal Testing Machine operating with a load cell capacity of 5 kN. A total of three specimens were prepared and tested for each sample.

Fig 3.5: Universal Testing Machine

3.5 Water Absorption and Thickness Swelling

Water absorption and thickness swelling of the three 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 2 h and 24 h to determine short and long-term water resistance properties, respectively.

Fig 3.6: Sample soaked inside distilled water

The weight and thickness of the sample were measured before and immediately after soaking and used to calculate water absorption and thickness swelling and reported as percentages of the values before soaking.

IV. RESULTS AND DISCUSSION

4.1 The Influence of Rice Husk Fibres on the Mechanical Properties of Polystyrene / Rice Husk Composites

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 4.1, 4.2 and 4.3, respectively. Young's modulus is frequently used as a marker to evaluate the rigidity of polymeric materials, and is used as such here The young mudulus of polystyrene / rice husk composites increased slightly with increasing rice husk fibre content up to 40% w/w, at which point the resultant composite young mudulus was 365 MPa as against the 2.5 – 7 MPa range of pure Polystyrene. Evidently, rice husk fibre incorporation into polystyrene via PBR matix 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.

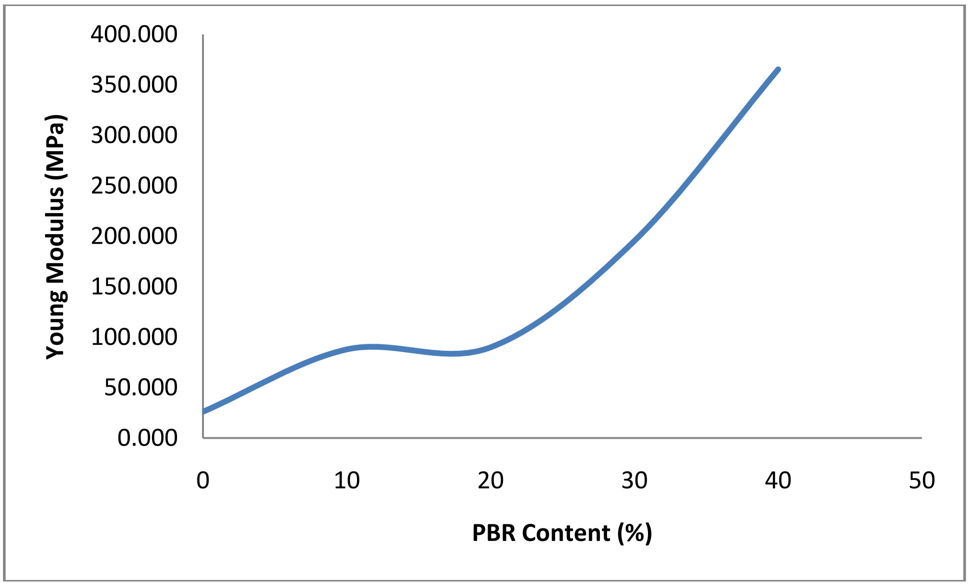

Fig 4.1: Effect of rice husk fibre incorporation with polystyrene on the Young's modulus

4.1.1 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% fiber loading and less than 1% at 40% fibre loading. for polystyrene/rice husk composites with increasing filler loadings (0%–40%) showed a gradual decrease from 9.64% to 0.76% (Figure 10). Polystyrene are ductile in nature while rice husk exhibit brittle behavior. Thus, the gradual increase in brittle behavior is due to the incorporation ofthe reinforcement material and may arise from interstructural progression in which fillerparticles are dispersed in the interaggregate space. At low filler loading, the matrix is notadequately 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

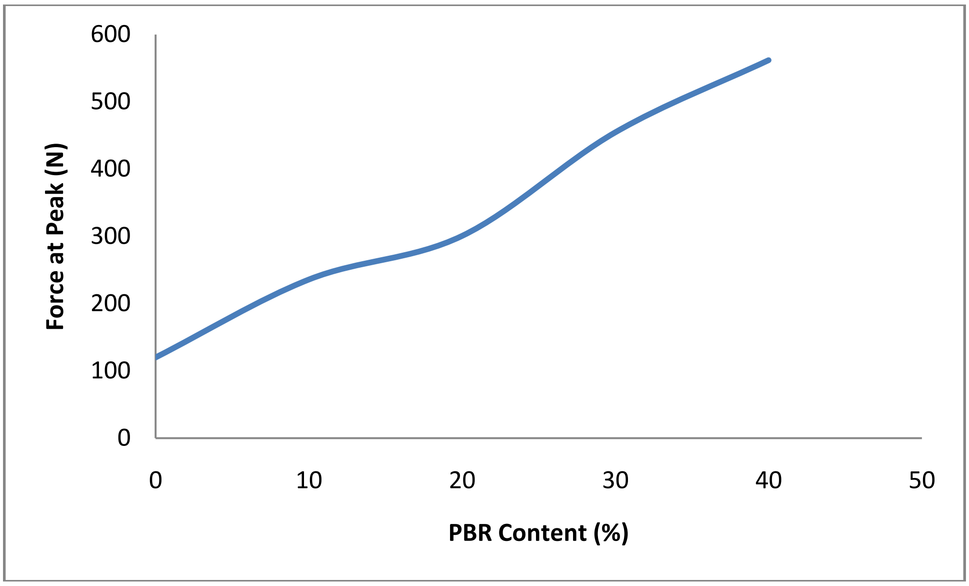

Fig 4.2 : Force at peak of the resultant Polystyrene / rice husk composites

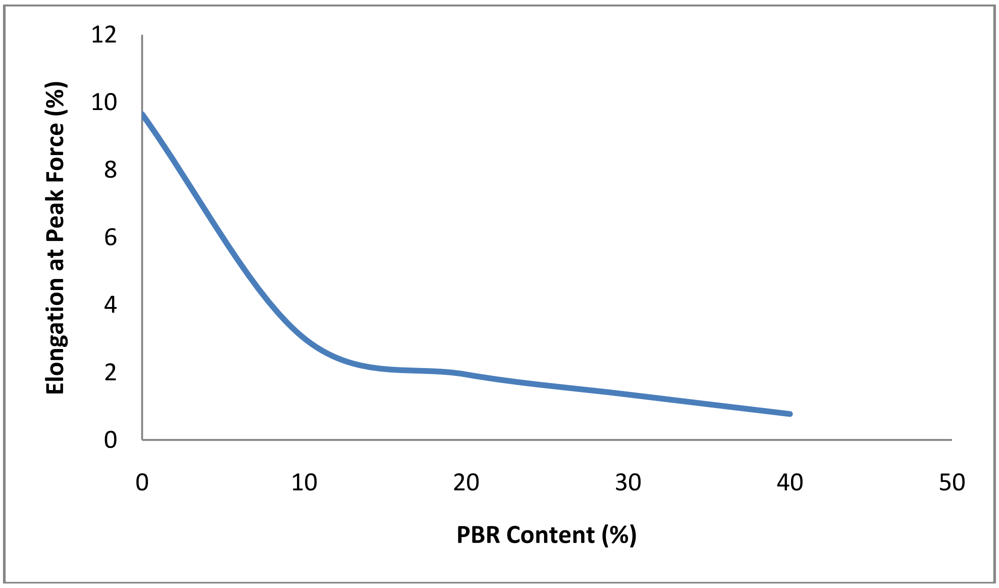

Fig 4.3 : Elongation at break of the resultant Polystyrene / rice husk composites

4.2 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 4.4 and 4.5, respectively. The water absorption of both polystyrene / rice husk composites increased continuously day by day untill 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 was 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.

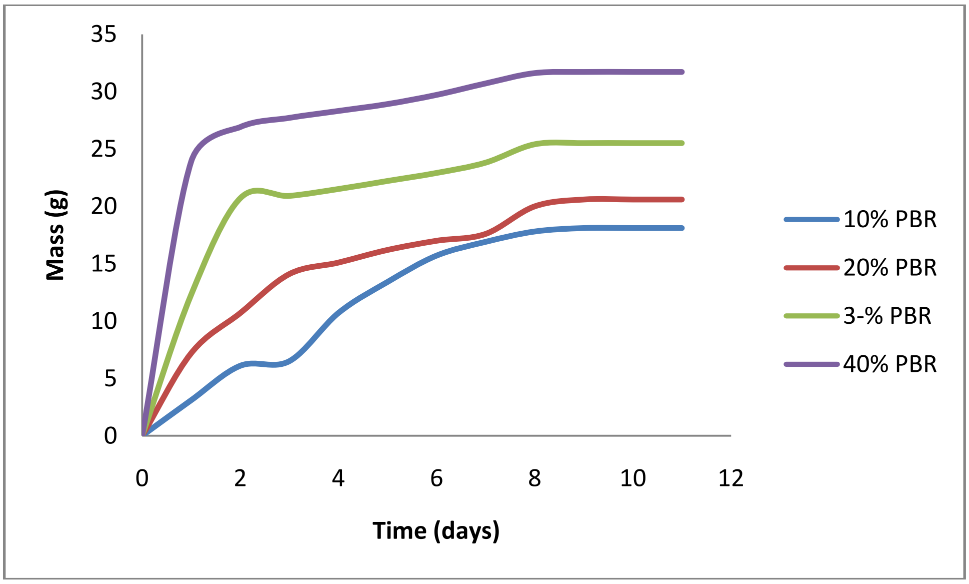

Fig 4.4 : Influence of rice husk content on the water absorption of Polystyrene/ rice husk composites

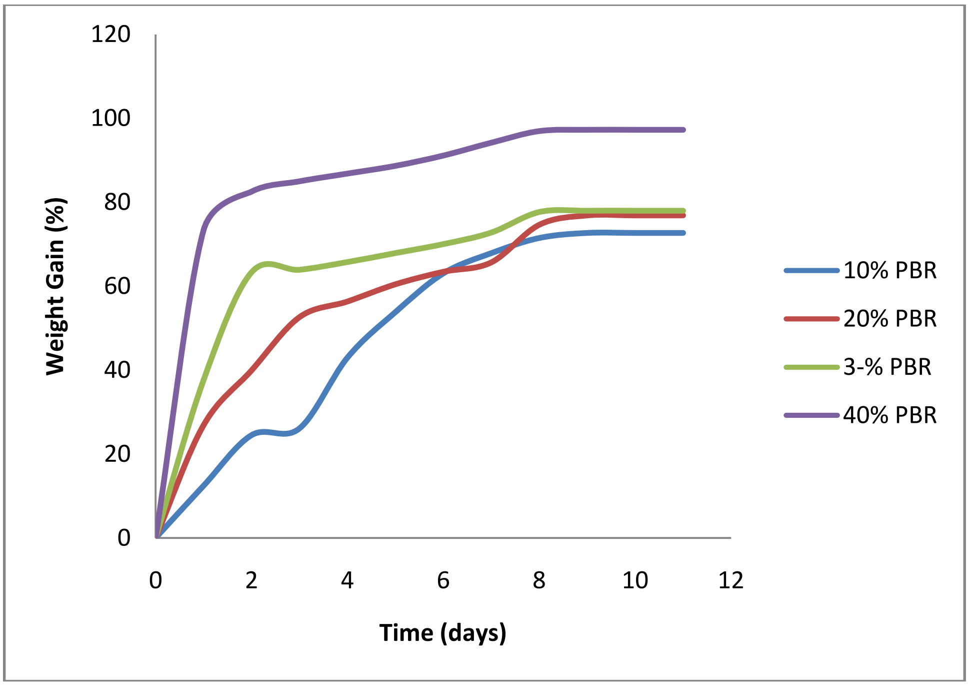

Fig 4.5 : Influence of rice husk content on the water absorption of Polystyrene/ rice husk composites after weight gain

V. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

From the research carried out, it was concluded that the use of rice husk as a filler in polystyrene composite would reinforce the strength of the composite. It was also discovered that at higher filler loading, the molecular mobility of the composite drops. Also, the incorporation of this filler material brings about an increase in the rate of water absorption. In summary, rice husk is a good filler material to improve the rate of water absorption and increase its resistance to failure.

5.2 Recommendation

More researches should be carried out on the mechanical properties of these composites and its usefulness to the industry. Also, an advanced mechanical sieving should be provided for effectiveness and comfortability.

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