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The Impact of Rice Straw Micro Fibres Reinforced Epoxy Composite on Tensile Strength and Break Strain

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Abstract— Rice straw residuals are considered one of the natural wastages that are found with huge quantities. Burning method is the commonly used way to get rid of these wastages, and this is done in an open area that causes harmful impact on environment. Rice residuals are observed to have good mechanical properties that could be usefully used. The present research focuses on rice straw due to the large amount produced relative to the rice husk. The measured responses were tensile strength and break strain of Rice straw microfibers reinforced epoxy composite, while the controllable variables were the filler size (small, medium and large) and filler volume fraction (3%, 6%, 10% and 15%). Experimental Results showed outstanding enhancement in the break strain especially for small RSF composite that reached over 350% in case of 3-wt %, enhancement in tensile strength was observed at small size RSF composite especially at 3wt% that reached 40%.

Index Terms— Polymer matrix composite, Rice straw microfibers, size effect, Volume fraction effect, Tensile strength, Break strain

1. Problem Definition and OBJECTIVES

The need to produce new environment friendly materials with mechanical properties that satisfy industrial needs was the motivation of the current work. This was accomplished through fabricating a composite material from rice straw (RS) microfibers and epoxy and then evaluating the mechanical characteristics through examining the effect of three factors which are volume fraction, fibres size and chemical treatment for the fibres. The target is to study the behaviour of this new material at different conditions and to explore the possibility of using it in different applications as a substitute to conventional materials.
The objective of this work is to Study the effect of filler size and volume fraction on the mechanical properties of epoxy reinforced with rice straw micro fibrils and to examine the effect of chemical treatment (Mercerization) of rice straw on the mechanical properties of the composite mechanical properties.

2. Introduction

Increasing the industrial products and expanding the manufacturing fields came along with the establishment of many environmental restrictions. This initiates a need for a kind of materials that satisfy the industrial requirements, such as high stiffness, high strength, low thermal expansion coefficient, low cost and do not violate the environmental restriction. A combination of many properties is often required and is hard to be achieved by conventional materials. In the current work, the used matrix is epoxy that is categorized as a thermoset polymer; this type of polymer is cross-linked material with high hardness and stiffness properties. It does not soften and cannot be reshaped after cur. Epoxy is the most common thermosetting polymer that is widely used as a resin for natural fibres [1, 2].
Rice comes in the second rank in the world's largest cereal crop. During the last 10 years global rice production is increased at rate 16.48 million tonnes per year. Rice residuals are mainly rice husk and rice straw. It was found that largest amount of residuals are produced by rice as a result of this continuous increase in the rice production rate [3].
Rice straw (RS) is the second rice byproduct, the average ratio between rise grains: rise straw: rice husk is 1:1.25:0.25. This justifies the reason for selecting straw rather than husk in the current work, as it is found with huge amounts much more than that of rice husk. Making use of it will have a larger impact [3].
RS is produced by 750 million tons annually; it is composed of leaves and stem, the stem has tubular and hollow structure. Rice straw has attractive properties such as low density. It has a reactive surface and it is available with low price, which allow it to be involved in many applications. The micro/nano fibrils that are formed of natural fibres have excellent mechanical characteristics and could be used as fillers in composite materials but it is not easy to reach good dispersion in the matrix [4, 5].

2.1. Mechanical Properties Investigations

Buzarovska A. et al. [6] studied the effect of using rice straw as filler with poly hydroxybutvrate-co-hydroxyvalerate (PHBV) copolymer at volume fraction of 20% and 30%. Their results showed that tensile strength is decreasing by increasing the

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filler volume fraction. This was due to the improper distribution of RS. It is suggested by the authors that using a comptabilizing agent or treating the surface prior mixing with the matrix may enhance the adhesion between the filler and polymeric resin [6].

Irene S. et al. [7] investigated the mechanical treatment of rice straw fibres aiming to explore the available applications for a composite of low density polyethylene (LDPE) reinforced with rice straw (RS); by testing the mechanical properties at different conditions and reaches the optimum. The three parameters investigated were volume fraction of RS wt % (2%, 5% and 6%), chemical treatment of rice straw (by sulphuric acid H_2SO_4, phosphoric acid H_3PO4 and sodium hydroxide NaOH) and fibre length of (2mm, 4mm and 6mm). Phosphoric acid at 1% concentration showed the highest results for tensile and flexural strength. 5% RS was the optimum condition for the volume fraction parameter, and it was observed that increasing the fibre length to 4 and 6 mm decreased the mechanical properties [7]. More reduction in the size was investigated, aiming to get better mechanical characteristics. A study by Han-Seung Yang et al. [8] examined the effect of rice husk flour (RHF) as reinforcement for polypropylene matrix on the mechanical properties of the composite. Different volume fractions were examined 10, 20, 30, and 40% by tensile test and impact test was performed using notched and un-notched specimens. Results showed that as the RHF volume fraction increases the tensile strength decreases due to poor bonding between RHF and matrix while tensile modulus increases. The impact test results for both types of specimens showed a decrease in the impact strength. It was observed that pre-treatment is required for the RHF before using it as reinforcement [8]. Although the previously mentioned work focuses on the treatment effect of rice straw fibres, yet the Author find it is important to explore the truth beyond the strengthening behaviour of untreated rice straw and further work will be done on treated rice straw.

2.2. Chemical Composition of Natural Fibres

Plants are formed of cells that differ in its physical characteristics according to the different amounts of its constituents. However, the existence of a rigid cell wall of thickness that varies from 0.1 to 10 µm is a common constituent in all the plant cells. This wall is responsible for the cell shape, mechanical strength, and adhesion between cells [9]. It is composed of microfibrils each of thickness 0.01-0.03 µm. The microfibril is the primary structural unit of the cell wall, its structure was found to be composed of dominated semi-crystalline cellulose core, which affect the fibre strength. As the cellulose content increases the fibre strength increases. This cellulose core is embedded in a matrix of hemicelluloses and lignin. The hemicellulose which; is connected with cellulose with hydrogen bond; has an essential role in the microfibirl composition which is binding the cellulose microfibril, while hydrophobic lignin provides stiffness for the cellulose- hemicellulose composite [10]. Thus, the plant cell wall provides the plants with strength that help them growing under different environmental conditions. Accordingly, plant cell wall is basically composed of cellulose, hemicellulose, lignin and other components such as waxes of the surface. The contributing percentage of each of these constituents varies according to the plant species, its growth stage and exact tissue type [9].

Figure (1) [9] shows a schematic illustration for the chemical composition of natural fibres.

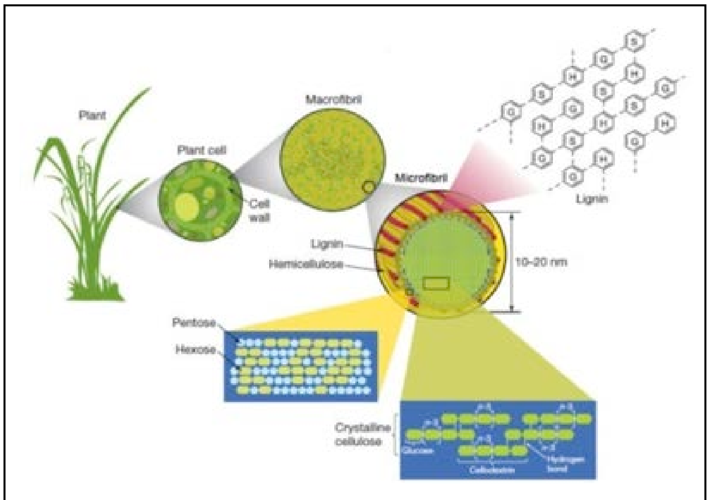

Fig. 1. Plant cell wall composition [9]

2.2.1.Cellulose

Cellulose is the primary material and the most available constituent. It contributes by 15-50% plant biomass dry weight. It is a linear polymer that is formed of D-anhydroglucopyranose units that are linked to one another through covalent bonds with β (1-4) glycosidic [9]. Cellulose has a hydrophilic nature due to the existence of hydroxyl groups in its composition as shown in figure (2) [11].

The type of cellulose controls the mechanical characteristics of the natural fibres. Cellulose types are classified according to their different cell geometry, such as solid cellulose which have microcrystalline structure of amorphous and crystalline regions, and slender rod cellulose same as crystalline micrfibrils. Cellulose is also characterized by its resistance to the strong alkaline effect. On the other hand it can be hydrolysed easily to water-soluble sugars through the acidic effect [10].

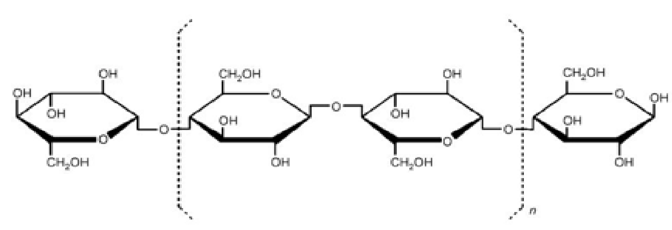

Fig. 2. Cellulose structure

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2.2.2. Hemicellulose

Hemicellulose is the second most available cell wall constituent. It contributes by 10-35% plant biomass dry weight [9]. This content highly affects the moisture absorption nature of the natural fibres [12]. It differs from cellulose in many ways. First, regarding its composition, hemicellulos is highly branched polymer that consists of different sugar units such as pentose which is polymer that contains five carbon sugars and hexoses, while cellulose is a linear polymer of 1, 4-b-D-glucopyranose units. Second, Hemicellulos is sensitive to alkaline effect unlike cellulose that is sensitive to acidic effect [10, 13].

2.2.3.Lignin

Lignin is a complex hydrocarbon polymer that composed of aromatic and aliphatic compounds, it has a hydrophobic nature and its main contribution in the plant characteristics is that it provides plants with required rigidity. Lignin is considered as a thermoplastic polymer of melting temperature around 170^{o} C. Unlike cellulose, lignin not hydrolysed by the acidic effect yet it is soluble by the effect of hot alkali [10].

3. Experimental work

3.1. Fibres Extraction and Cleaning

The as-received rice straw (RS) as shown in Fig. 3 is composed of fibres and leaves, the current work is focusing on the rice straw fibres (RSF). Accordingly, a process of leaves removal takes place to extract desired RSF. Afterwards, the extracted fibres from rice straw are cleaned using with hot water at about temperature of 80 C for 1 hour and then left to dry for 24 hours. In order to insure there is no water entrapped in the rice straw fibres, the weight of fibres is measured before cleaning and after 24 hours, if RSF weight before and after cleaning is equal or the weight after cleaning is slightly less than initial weight, then the water inside fibres dried and no entrapped water. Accordingly the rice straw fibres are ready to enter the second phase of the fabrication process, which is grinding. If RSF weight after cleaning is higher than the initial weight then RSF is left for more time to dry.

Fig. 3. Rice straw cleaning process

3.2. Microfibers preparation

The next stage in preparing the rice straw microfibers is grinding, using the grinder with knife will be effective with natural fibres as shredding is more suitable than impact using mortar and pestle for example.

As shown in Fig. 4 grinding took place at constant grinding speed and as the grinning time increases finer size produced, many trials with this factor it was observed out of experimental trials that 20 minutes is a suitable time for grinding the rice straw. For output consistency it is recommended to have the fibres with approximately similar diameters and to cut the fibres in to equal segments with length compatible with grinder cup diameter.

Sieving concept was implemented on the rice straw for the purpose of size classification. Small size RSF passes down through mesh (A), the remaining large RSF sieved again using large mesh (B). The resulted sizing are classified as follows:

Small size range from (20μm - 100 μm), the medium size ranges (greater than 100μm - less 200 μm) and the large size range is (200μm - 250 μm).

Fig. 4. Grinder and Rice Straw Fibres [11]

3.3. Specimen specifications and fabrication

The mould is designed to produce specimens for the required tensile test needed in the experiment. This design is guided by specimen dimensional specifications stated by ASTM D638 [14]. The preferred specimen as stated is type I that has 7mm thickness or could be less; 7 mm thickness is suitable for the manufactured composite that has filler that has relatively large volume and also to insure the completion of tensile test without slipping of the specimen.

The required combinations for the current work are small, medium and large with volume fractions (3%, 6%, 10% and 15%) for each size and the specimens are fabricated according to the following steps:

1- Weight the required quantities of resin (A) and hardener (B) with ratio 2:1 as recommend by the manufacturer.
2- Hardener is mixed with the filler and start them mixing for 2 minutes (hand mixing).
3- Mixture of hardener and filler is added to the resin and start mixing for 5 minutes.
4- The screws of the mould should be tightened well to prevent leakage of the material from the side spacing.
5- Mould is cleaned and coated with glycerine to prevent the specimen from sticking to the mould and also to facilitate the specimen release after curing.

6- The mixture is ready to be poured in the mould, and it is left for 24 hours for curing.
7- After 24 hours the specimen is removed from carefully from the mould and it is ready for the tensile test.

4. Main Results

Three samples for each combination were tested to determine the tensile strength and break strain. As shown in figures 5, 6 and 7 the addition of the rice straw fibres increases the ductility of the material, this phenomenon was observed in all tested samples. Yet, 10-wt % in small size and 6-wt % in medium and large size showed highest ductility. Highest strength was observed in the 3-wt % for all the fibre sizes, this may attribute to the change in the composite nature at high volume fraction so that fibres characteristics were dominate rather than having homogenous composite of both matric and filler properties matrix.

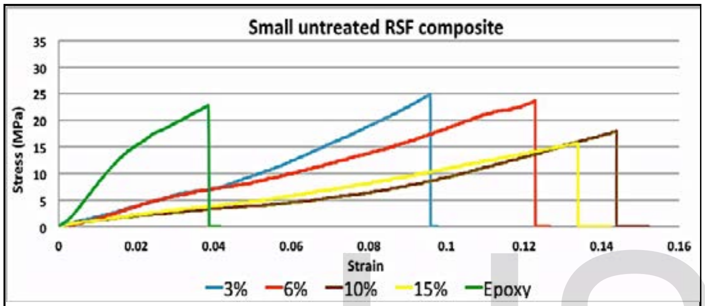

Fig. 5. Stress Strain curves for small size RSF composite

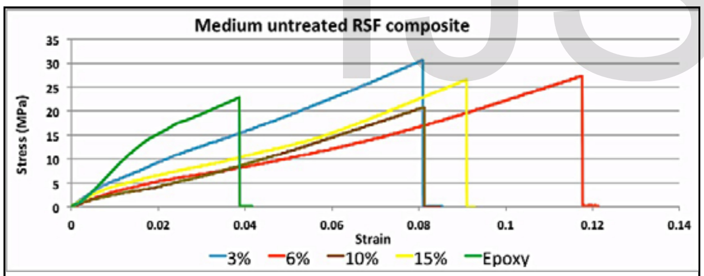

Fig. 6. Stress Strain curves for medium size RSF composite

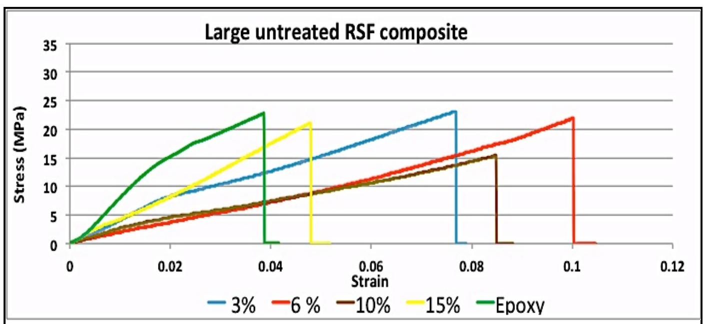

Fig. 7. Stress Strain curves for large size RSF composite

Figure (8) shows the relation between tensile strength of different RSF composite volume fractions at the three tested sizes, from the pattern of tensile strength, it was observed that as the volume fraction increases the tensile strength decreases till it reach a certain limit of 10-wt % after that increasing in the tensile strength was observed for both medium and large sizes only.

Results showed that among all tested volume fractions highest tensile strength values are found at volume fraction 3-wt %, which indicates that the contribution of the filler was the best among other volume fractions.

Another observation was indicated here is that the highest tensile strength enhancement among all tested combination was for the small size RSF of concentration 3-wt %, this results agrees with the previously mentioned hypotheses that small sized RSF give higher strength for the composite more than what observed from medium and small sizes, results of this combination showed 40% enhancement in tensile strength over pure epoxy. On the other hand no significant enhancement in the tensile strength is found for epoxy reinforced with large fibres. This is expected to be due to agglomerations that affect the bonding between filler and matrix.

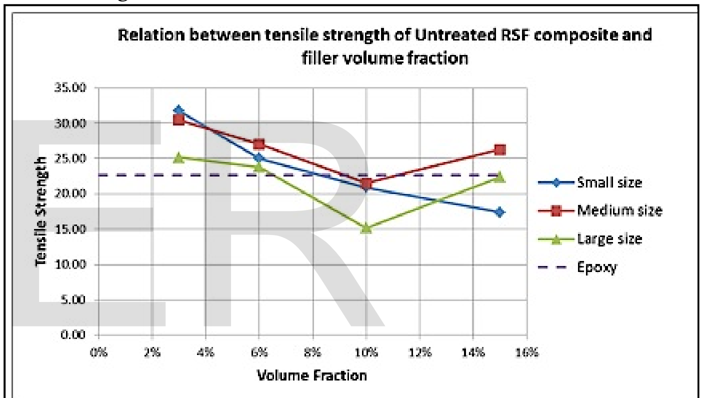

Fig. 8. Variation of tensile strength with fibre volume

Figure (9) shows the relation between break strain and volume fraction of the RSF composite for all tested sizes, as it is clearly shown enhancement in break strain was detected for all volume fractions at the three tested sizes although small RSF size showed highest values that reaches up to 350% enhancement over pure epoxy break strain.

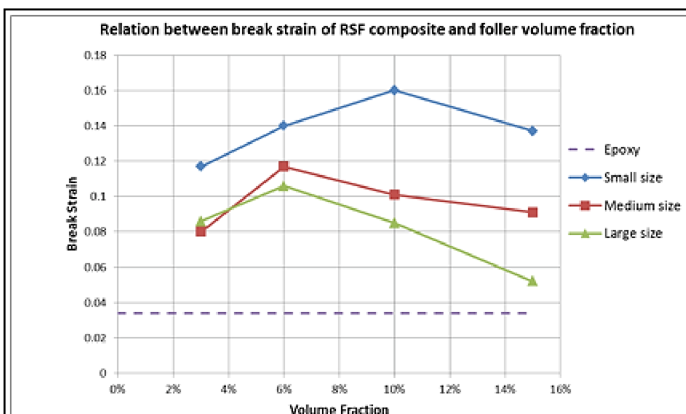

Fig. 9. Variation of break strain with fibre volume

5. Conclusions

- The small size RSF composite showed higher strength than medium and large sizes.
- No enhancement in strength was observed for large size RSF composite due to agglomeration of fibres.
- The break strain of the RSF composite showed great enhancement that reached over 350% in case small size RSF with concentration 3-wt %.
- Small size RSF with 3-wt % showed the best results in both tensile strength and break strain.

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