The influence of particle size on the mechanical performance of epoxy coir composites

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Abstract:

Recently, the employment of agro waste materials as reinforcement for polymersis considered asa milestone on preparing polymer composites. Thiswork is focusing on preparing natural fibers composites and studying theirmechanical performance afterwards. Coir particles are considered as a low cost natural fibres material which can be used as a filler with Epoxy resin matrices. The weight fraction of coir fibres in epoxy resin was 10.0 wt.% with different grain size of (950, 750,250)μm.Hand lay -up method was used to prepare composites of Epoxy reinforced with coir particles. Mechanical properties of Compression and Hardness were examined. Scanning electron microscope (SEM) was utilized to investigate the fracture of fibres and their de-bonding afterwards. Results showed that the Brinell hardness was increased in parallel with the decrease in particle size, while compression strength findingsshowed different behaviour represented bygradual increment that was associated with the increment of particle size .

Keywords: Coir, Epoxy, Composites, Brinell hardness, Compression, Hand lay-up

Introduction:

Composite materials are used in number of elements, which include aerospace, automotive, structural materials, plastics, wrapping, and oilfield supplies [1-2]. The inspiration to present natural reinforcements to matrix is to lessen the manufacturing value, sell the recyclability, reusability of the waste, and flip it into a value-introduced product .

Composites' characterization depend on the reinforcement with fillers. Composites have many remarkable features such as lightweight, higher strength and stiffness, resistance to chemical solutions, corrosion and temperature resistance, durability, flexible to design samples, with lower thermal conductivity and higher dielectric stability. Also, compositeshave significant contributes for reduction in eco-footprint and CO2 emission [1.[

Natural fibres and consequently, the compatibility has been improved between the fibres and the polymer matrices. Such required improvement will lead to a notable mechanical performance for the resulted composites [5.]

Coir fibre is considered as one of the most efficient fibres that is used to synthesize natural fibres composites in order to enhance the mechanical properties. Coconut fibre can be extracted from the outside shell of a coconut fruit. The standard expression, name used by science, and the groups of plant of coconut fruit fibre are Coir. There are two types of Coconut fruit fibres – dark brown fruit fibre that can be get from mature coconut fruits and white fruit fibres extracted from tender coconuts. Dark fruit fibres have thicker and stronger shells with higher abrasion resistance, while the white shell consider as a smoother and finer, but also weaker (6).

Coir fibre has a high strength and rigidity properties which find its applications in producing novel composites.Moreover, the structure of coir cell are crystalline cellulose helically in a matrix (7-8).

The present work is aiming to prepare coir particle-filled Epoxy as bio-composite material as well as investigating the mechanical properties compared to neat Epoxy. This study found that coir particle-filled Epoxy has a better surface morphology, In conclusion, coir with particle sizes in powder (dust) form has been proven to be potentially useful in improving the hardness strength of composites, while coir particle size of 950 µm was the best for compression strength.

Natural fibres NFs such as wood, jute, kenaf, hemp, sisal, pineapple, rice husk have many applications and others has been proved to improve the mechanical properties of polymer composites. Other examples of NFs that can be used instead of wood fibres for strengthening composites are bamboo, spent coffee ground (SCG), wheat, cereal straw, flax straw, corn husk, corn pith, and bagasse (2).

The compatibility of some natural fibres with both thermoplastic and thermosetting polymers has become a considerable problem according to the poorly prepared surface quality and the hydrophilic nature related to these fibres that makes them inconsistent with hydrophobic matrices. As a result, the interfacial strength that connect the fibres and the polymer matrices is weak which lead to a significant deterioration in mechanical performance (3-4).

For the aforementioned reasons, the chemical treatment has become an indispensable solution for this problem as this kind of treatment is working on improving the surface quality of the

Previous Studies:

Sakthivel et al. [9] used coir and luffa fibres to develop the Polypropylene PP matrix composites. The study showed that these additives that were added to the matrix led to enhancement in hardness, rigidity of flexural, impact, and tensile strength.

Mark et al. [10] were embedded carbonized coconut shell particles with different particle size as additives in PP composites; the amount of additives were between (0–40%) by weight. The composite samples were synthesized by using injection technique and the findings highlighted an increment in hardness, and strengths in both tensile and flexural. However, Young's modulus and elongation at break were decreased with rising the content of carbonized coconut shell particulates.

Noor et al. [11] studied the effect of different grain size of coir fibre on some mechanical properties of epoxy-coir composites such as strength of flexural and impact. The samples were made by hand lay-up method. The additives were added at 10 % by weight of Epoxy resin. The outcome showed an improvement in the aforementioned mechanical parameters.

.2Materials

Coconut shells (coir) were purchased from the local markets, and employed as reinforcing agents. Epoxy resin (Sikadur-52, China) with a density of 1.12 gm/cm3 bought from a national company in Iraq. The Epoxy and its hardener were blended together with a ratio of 2:1, which means that 1000 gm of the resin mixed with 500 gm of the hardener .

.2.1Preparation of composite

A dried fabric with a detergent were utilized to clean the coir fibres. To guarantee a fully dryness for the fibres, an exposure to sunlight for a couple of days was adopted. Then, an oven (Memmert, Germany) was employed for three hours adjusted at 55 oC. Afterwards, a hammer was employed to crush the fibres into tiny coir fibres. The obtained dried fibres were then processed with (NaOH) solution of 2.0% w/v concentration for 3h .

The aforementioned chemical treatment with NaOH was adopted in order to remove moisture content from the fibres .

After completing the treatment process, the shells were taken out and soaked in distilled water, and then dried by following the same steps that were discussed earlier. Consequently, by using hammer all fibres were crushed to a smaller pieces .

Finally, coffee mill was used to grind fibres into fine particles. These fine particles were sifted through special meshes varied from (0.075 -1.018) µm to

obtain reasonable particles geometries of different size. The final obtained particles were employed to reinforce epoxy. The technique of hand lay-up was used to manufacture the samples. A special mold made from aluminium was cleaned and oiled to ensure an easy extraction of the samples.

10.0 wt. % of fibres were employed to synthesize the composites. The fibres were shared the same glass beaker with Epoxy. A mechanical stirrer was employed to mix the resin and the fibres gently represented by 100 rpm to prevent the formation of air bubbles. After the temperature of solution reached 25 ,˚the hardener was slowly added to the mixture and a consistent stirring of 100 rpm was performed until the mixture started to condensate to be heavy. Then, the mould was employed to include the mixture that was cured for 24h at 22 oC. Finally, the samples were easily removed from the mould and put for 3h in a vacuum oven (Memmert, Germany) at 60 oC in order to achieve the required cross-linking for the thermoset resin of epoxy .

.3Testing procedure

.3.1Scanning Electron Microscopic analysis (SEM)

The surface morphology and distribution of fibres in the matrix were investigated by employing SEM (TESCAN MIRA3, Czech Republic). The specimens of different grain size were explored by the microscope to investigate the type of fractures of fibres in the resin in order to find the relation between the morphological properties and the mechanical properties. The specimens were mounted onto SEM stub using electric conducting with double-sided carbon adhesive tapes to avoid the detrimental effect of charge build-up that may form due to the contact of the specimens to the electron beams of the microscope .

.3.2The compression test

Compression test was performed by using a physical hydraulic press with the maximum load (7.5 KN). All samples were cut according to (ASTM -D 695) where the investigation was used three samples of composite. The compressive load was increased until the failure of the sample occurs and the value of compression were calculated.

The following formula was used to calculate the compressive strength (12).

$$Compressive\ strength, \sigma c = \frac{F}{A_o} \quad [1]$$

(F): is the Load until failure

(A_o) area of sample

.3.3Brinell hardness testing

This kind of hardness can be clarified simply by creation of an indentation with an indenter of spherical geometry of 5 mm diameter which is manufactured from hardened steel. Loads of 1000 N was applied at various points over the surface of the specimens for 30 sec. The indentation diameter, 'Di' is measured by employing a specific objective lens. Brinell Hardness Number BHN can be calculated according to the following formula (13)

$$BHN = 2F/\pi D(D - \sqrt{D^2 - d^2})) - - - [2]$$

Where (F) is the applied load in N, (D) is the steel sphere diameter in mm, and (d) is the indentation diameter measured by an objective glass in mm.

.4Result and Discussion

.4.1Brinell Hardness

The principle of hardness can be defined as an amount of the plastic deformation that the material can suffer under the influence of external stress [14]. Epoxy reinforced with particle (coir fibre) improved the hardness of the material due to increased resistance to plastic deformation. Figure (1) shows an average BHN for the neat polymer and epoxy-coir composites. It can be seen that the BHN decreases as the particle size went higher. Samples with coir grain size of 950μm contributed in hardness decrement to (152.19) and the sample of grain size of 750μm showed a decrement of BHN to be 201.11. On the other hand, sample of the particle size of 250 μm showed an improvement in hardness to be 296.86 compared to the neat polymer. Hence, there is a progressive decrement in BHN with a higher valuesrelated to the particle size. The enhancement in hardness associated with small grain size can be ascribed to the brittleness of the sample that makes the composite lose its elastic and plastic properties [15]. Furthermore, the higher value of hardness gives an indication about good adhesion between the fibre and the matrix which means that voids and pores formation around the fibers minimized to the best possible level [16]. The small grain size and a good dispersion of particles (homogenous distribution) in composites lead to enhance hardness values. In addition, the smaller particle size support the bonding in the composites on the surface of the matrix. In that case, the latter will be able to accept greater load which consequently lead to improve the hardness [17]. On the other hand, the large particles are acting as a resistive barrier for either flow of material (18).

These findings are agreed with Faten Rashi et al [14] whom found that hardness number was increased with low particle size of (graphite or silica) and this led to the selection of particles of small sizes which facilitated the process of penetration into the base material and into the interface of fibre network.

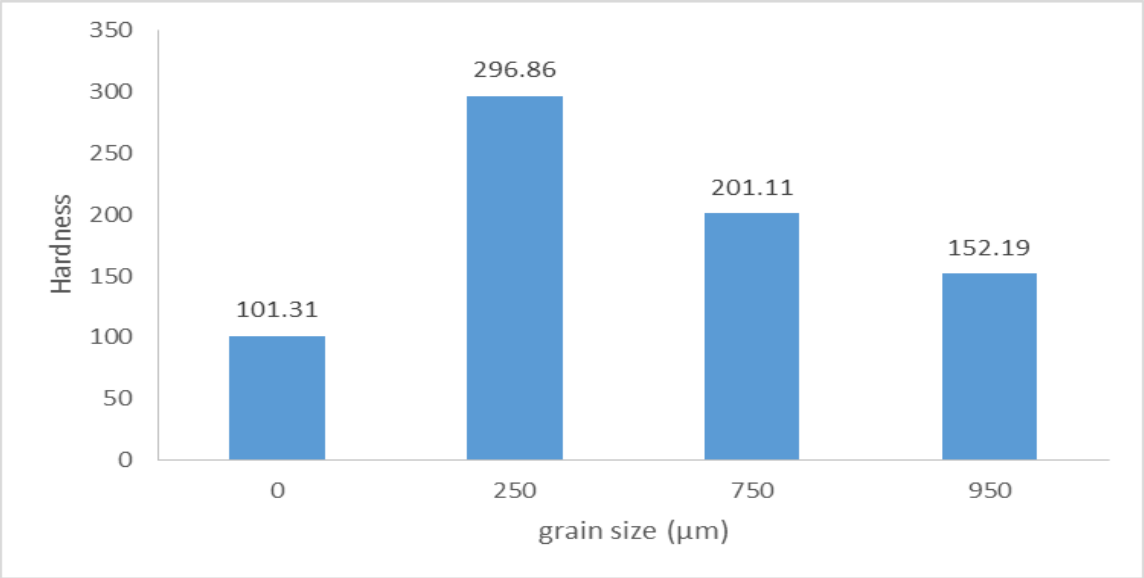


Figure (1) Hardness of coir particles Epoxy composites

.4.2Compression test

The compressive behaviour of composites as well as the neat polymer are shown in Figure 2. Inversely to the Hardness, the compressive strength rises with the increment of the particle size. The particle size of 750 µm shows a high value of compressive strength represented by 67.56 MPa and particle size of 950 µm shows the highest value of compressive strength represented by 70.52 MPa .

The compressive strength can be improve progressively by increment in grain size. This can be attributedto the stress concentration around the particulates that increases with a hike in the particle size. Also, the specimens with a smaller grain size are not provide an enough barrier to the matrix under the influence of the compressive load due to the concentration of stresses around the particulates that led to a quick failure [19].Due to the aforementioned explanation, the coir composites reinforced with small grain size are not suitable for undergoing to higher loads of compression .

Moreover, the compressive strength of a specimen reinforced with fine particulates is lower than other specimens reinforced with greater coir particle size.

This can be attributed to the compaction and de-bonding between particles which are possibly occurred with fine particles. The higher density of specimens of fine particles compared to those ones reinforced with medium or large particles size lead to severe cracking. Breakage can be observed across the specimen reinforced with lower particle size while the cracks in a specimen with big particle is little. This is because the large particles reinforced the neat polymer are resisting the crack propagation [20.[

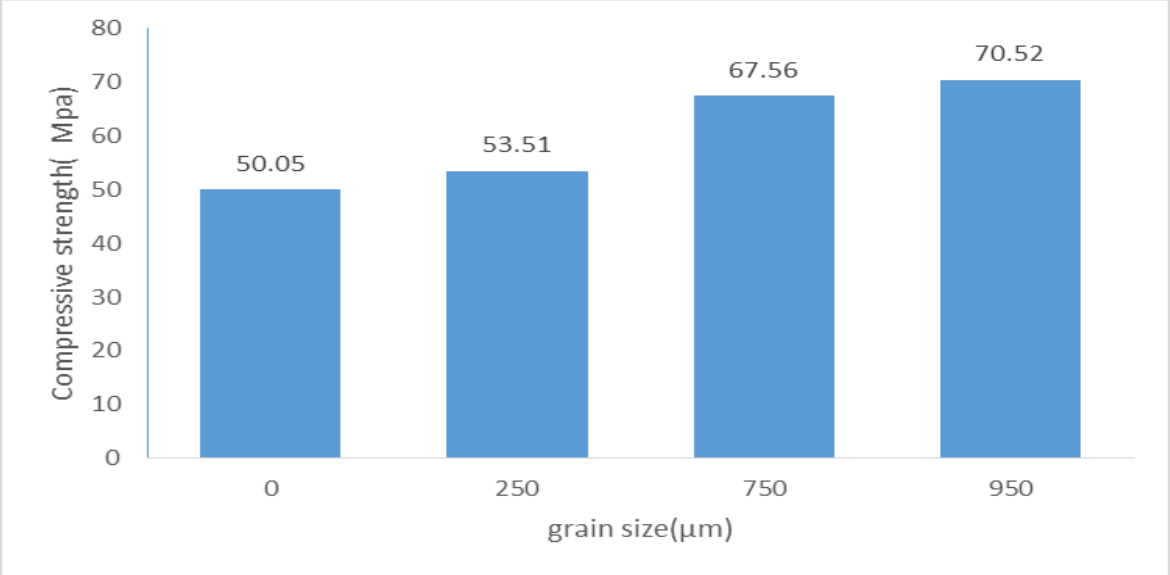
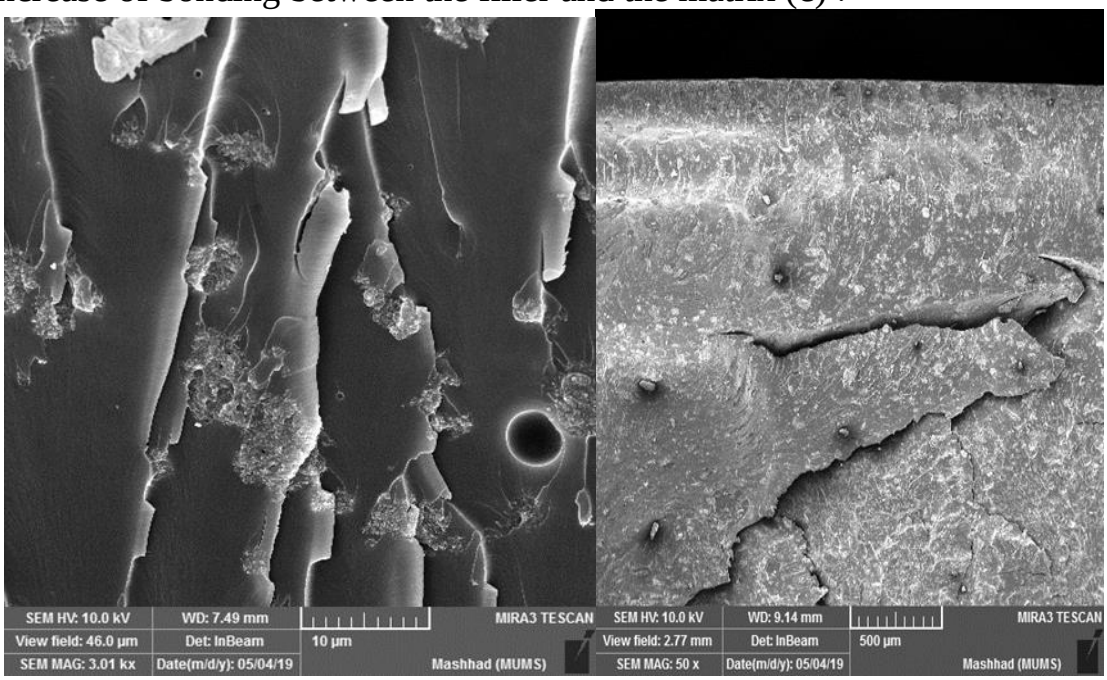


Figure (2) Compression strength of coir particles Epoxy composites

.4.3Morphological findings

The findings related to morphology of compression fractured composites are investigated by employing SEM. Figure 3 shows these findings. The main defects that can be mentioned in the morphology are ascribed to the formation of voids, brittle fracture of the Epoxy, and de-bonding of the resin /particulate. The SEM of samples majorly show the brittle fracture which is occurred due to the crack propagation through the samples which is intimately associated with the breakage of the composite. De-bonding of coir particles from the matrix is also clearly noticed in samples (a). As a result of the applied compressive load,the breaking of adhesive bonding between the matrix and the particles wasoccurred. The presence of voids in composites (a) is greatly affected by the movement of the coir grains from their original positions during loading to the ultimate point. It is noticed that there are a clear brittle fracture in epoxy areas, pull out and breakage into fibre regions for all the samples as shown in figure. According to SEM, the formation of

cracks and material removal on the surface are decreased; this is due to increase of bonding between the filler and the matrix (c) .



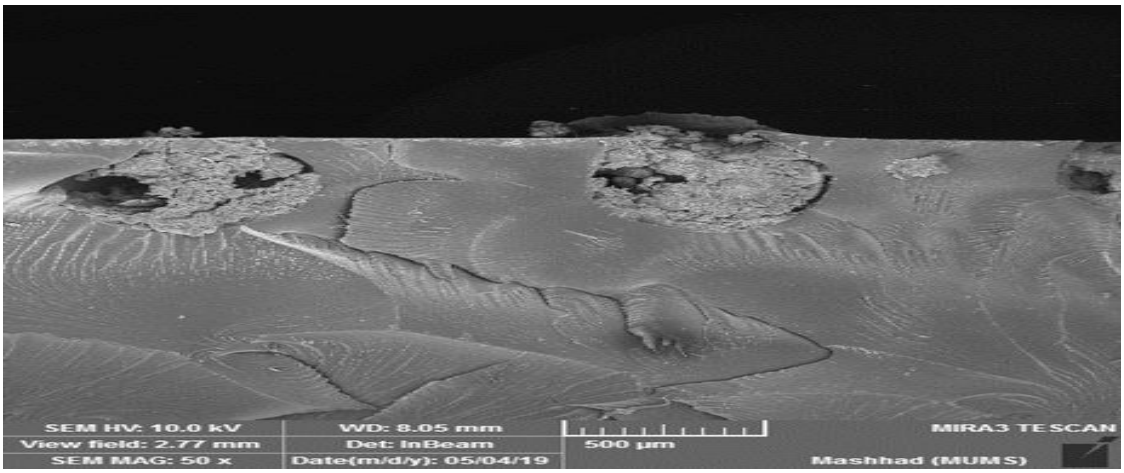


Fig. 3 SEM micrographs of the fracture surfaces of the composites,(a)de-bonding of coir fiber,(b)Fracture surfaces,(c)grains distribution in pure Epoxy.

Conclusion

In this work, coir particles with different grain size are used to reinforce epoxy resin. The following conclusions can be given:

The addition of coir in epoxy resin led to improve the hardness and compression strength .

Chemical treatment of the coir fibres showed significant improvement in the characteristics ofthe surface which consequently led to an improvement of bonding between the fibres and the epoxy.

(3Compressive strength of the composites was increased with the higher grain size of the coir fibres while hardness showed an increment with smaller grain size.

(4From the SEM images, it is clearly noticed that there was a formation of voids, brittle cracks, and de- bonding that was associated with compression test .

Further Work

The employment of graphene to improve the mechanical and physical properties of natural fibers composites will be in the scope of the authors' scientific interests .

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تأثير الحجم الحبيبي على الاداء الميكانيكي لمتراكبات الايبوكسي – الياف جوز الهند

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مستخلص البحث:
مؤخرا، تم اعتبار استخدام الألياف الطبيعية كمواد تقوية للمواد البولمرية لصناعة مواد متراكبة هدفا رئيسيا مهما. يركز هذا العمل على تحضير متراكبات بولمرية باستخدام الياف طبيعية كمواد تقوية، ومن بعدها اختبار السلوك الميكانيكي لهذه المواد المتراكبة. تعتبر ألياف جوز الهند اليافا طبيعية ذات كلفة مالية منخفضة يمكن استخدامها لتقوية راتنجات الأيبوكسي. الكسر الوزني المستخدم في عملية التدعيم هي 10% مع احجام حبيبية مختلفة لألياف جوز الهند (250، 750، 950) مايكرومتر. أستخدمت تقنية القولبة اليدوية لتصنيع المواد المتراكبة متمثلة بالأيبوكسي المدعم بألياف جوز الهند. تم اختبار السلوك الميكانيكي للمواد المتراكبة حيث أظهرت النتائج زيادة في قيم صلادة برينل مع تناقص قيم الحجم الحبيبي للألياف. أضافة الى ذلك، أظهرت النتائج الخاصة بمتانة الأنضغاط زيادة تدريجية مع زيادة الحجم الحبيبي لألياف جوز الهند. استخدم المجهر الألكتروني الماسح لغرض التعرف على طبيعة الكسر الحاصل في الألياف أضافة الى طبيعة فك الأرتباط بين الألياف والمادة المضيفة نتيجة لتأثيرات اجهاد الأنضغاط المسلط على المواد المتراكبة.

الكلمات المفتاحية: ألياف جوز الهند، الأيبوكسي، المواد المتراكبة، صلادة برينل، الأنضغاطية، تقنية القولبة اليدوية.