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Potential of using coconut shell particle fillers in eco-composite materials

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ABSTRACT

Morphology and mechanical properties of coconut shell particles reinforced epoxy composites were evaluated to assess the possibility of using it as a new material in engineering applications. Coconut shell filled composites were prepared from epoxy polymer matrix containing up to 30 wt% coconut shell fillers. The effects of coconut shell particle content on the mechanical properties of the composites were investigated. Scanning electron microscopy (SEM) of the composite surfaces indicates that there are fairly good interfacial interaction between coconut shell particles and epoxy matrix. It was shown that the value of tensile modulus and tensile strength values increases with the increase of coconut shell particles content, while the impact strength slightly decreased, compared to pure epoxy resin. This work has shown that coconut shell particles can be used to improve properties of epoxy polymer composite to be used in eco-buildings.

1. Introduction

Public attention is now being placed on the environmentally gentle composite materials made from natural fillers and polymeric materials. Eco-composites are made of natural materials that are non-toxic and biodegradable. They are attractive because they are usually safer to handle and work with and environmentally friendly. The development of eco-composite materials has accelerated rapidly, primarily due to improvements in process technology and economic factors [1,2].

Natural fillers (NF) reinforced materials offer many environmental advantages, such as reduced dependence on non-renewable energy/material sources, lower pollution and greenhouse emission. Natural lignocellulosic fillers (flax, jute, hemp, etc.) represent an environmentally friendly alternative to conventional reinforcing fibers (glass, carbon) [3,4]. Advantages of natural fillers over traditional ones are their low cost, high toughness, low density, good specific strength properties, reduced tool wear (non-abrasive to processing equipment), enhanced energy recovery, CO_2-neutrality when burned, and biodegradability [5].

Many research groups have directed their work towards defining numerous combinations of biodegradable matrix/natural fillers in order to promote new classes of biodegradable composites with improved mechanical properties, as well as to achieve products with lower cost. Among many investigated natural fibers in this area, different fillers have the significant importance. For example, the development of wood flour composites has been actively pursued [6]. With the increasing consumption of wood-based raw materials, their substitutions were inevitably needed.

Recently, there is a growing interest in agricultural waste as a substitute for wood-based raw materials. Among the various agricultural straws, coconut shell could be very interesting material as filler in biodegradable polymer composites, due to its good thermal stability compared to other agricultural waste [6,7]. The coconut shell can be easily crushed into chips or particles, which are very similar to wood particles or fibers. The coconut shell is mainly consisting of carbohydrate components such as hemicelluloses, cellulose, and lignin [8].

Coconut (Cocos nucifera) is a member of the palm family. The coconut palm is used for decoration as well as for its many culinary and non-culinary uses; virtually every part of the coconut palm has some human use. Coconut shell is non-food part of coconut, which is hard lignocellulosic agro-waste. Coconut shell is 15–20% of coconut [8]. The coconut husk, or mesocarp, is composed of fibers called coir. The inner stone or endocarp is the hardest part of the nut called shell. Adhering to the inside wall of the endocarp is the testa, with a thick albuminous endosperm, the white and fleshy edible part of the seed. Fig. 1 shows the photograph of coconut.

A lot of research has been done on natural fiber reinforced polymer composites but research on coconut shell particles fillers based polymer composites is very rare. Against this background, the present research work has been undertaken, with an objective to explore the potential of using coconut shell particles as reinforcement in polymer (epoxy) composites.

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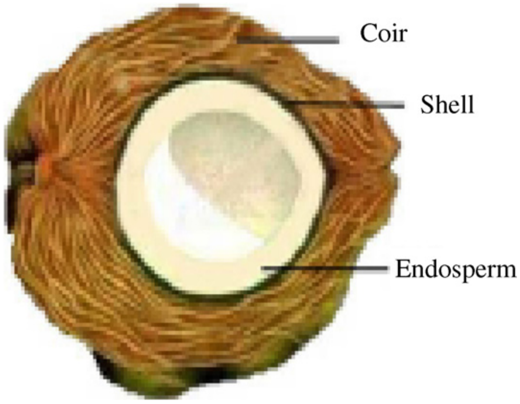

Fig. 1. Photomarcograph of coconut.

Fig. 2. Photomacrograph of the sieve coconut shell particles.

2. Materials/equipment

The coconut shell used in this study was obtained from coconut seller in Zaria, epoxy resin and hardener was purchased from Chemical shop in Kaduna. Equipments used in this research are Metal mold, hydraulic press, Avery Denison impact tester, micro-hardness tester, and Instron tensile machine.

3. Methods

The coconut shell was dried and grinded into coconut shell powder, the powder was sieve accordance with BS1377:1990 standard. 100 g of the coconut shell powder was placed unto a set of sieves arranged in descending order of fineness and shaken for 15 min which is the recommended time to achieve complete classification of the particles, the particle that will be retained below BS. 100 μm was used in this study. The photomacrograph of the sieve coconut shell particles is shown in Fig. 2.

Metal molds were used in the production of the composite samples. Each mold has a cavity to accommodate the composite samples. The dimensions and shapes of cavities were made according to the size and shape of the samples as per ASTM Standard D 638-90 for tensile testing and ASTM Standard D 790-97 for impact test (ASTM) [9].

Epoxy, hardener and the coconut shell particles were mixed in a container and stirred for 5–7 min. Before the mixture was placed inside the mold, the mold was polished with a release agent to prevent the composites from sticking onto the mold upon removal. Finally, the mixture was poured into the mold and left at room temperature for 24 h until the mixture hardened. When the composite is hardened, it was removed from the mold.

Studies on the morphology of the coconut shell particles, epoxy matrix and the composites were carried out using a SEM, model Leica Cambridge S-360. Charpy impact strengths of the specimens (120 mm × 10 mm × 4 mm) were determined with an impact tester (Chengteh China, Model JC-25 4J) [9]. The tensile strengths and tensile modulus were measured using Instron machine (model 5564) with a strain rate of 0.002 S^{-1}, at room temperature, according to ASTM D 638-90 [9]. Test samples were 3.5 mm thick, 6.0 mm wide and 60 mm long. The photomacrograph of the tensile test samples is shown in Fig. 3, while Figs. 8–10 show the stress–strain curve of the tensile test.

4. Results and discussion

The XRD pattern of the coconut filler reveal that the major diffraction peaks are 20.68°, 26.53°, 35.41° and 40.00° and their inter-planar distance, 2.24 Å, 2.03 Å, 1.99 Å 1.49 Å and 1.39 Å, and their relative intensity of X-ray scattering are 34.18, 100.00, 88.5, 29.04, 16.15. Phases at these peaks as Mg_2Si, C, SiO_2 Al_2O_3 and MgO, this revealed that this particle has some of the composition of hemicelluloses, cellulose, and lignin that has been confirmed by the literature (see Fig. 4) [3].

The morphologies of the Coconut shell particle and the composites by SEM with EDS are shown in Figs. 5–7. Morphological analysis using SEM clearly shows difference in the morphology of the polymer composites when compared with the morphology of the coconut shell filler and the polymer matrix separately (see Figs. 5–7). The microstructure clearly shows that when the coconut shell particle was added to the epoxy matrix, morphological change in the structure take place.

The microstructure of the coconut shell particle reveals that the size and shape of the particles vary; however, they can be sorted into three main groups – prismatic, spherical and fibrous. The prismatic particles consist mainly of Si and O. The spherical ones contain Si and O as well as Ca, Al. The fibrous ones consist of only C as a result of the EDS scan in rectangle (see Fig. 5).

The microstructure of the matrix (epoxy) is shown in Fig. 6. The structure reveals chain of lamellae and interlammeller amorphous

Fig. 3. Photomacrograph of the tensile test samples: (a) Control samples; (b) Reinforced samples.

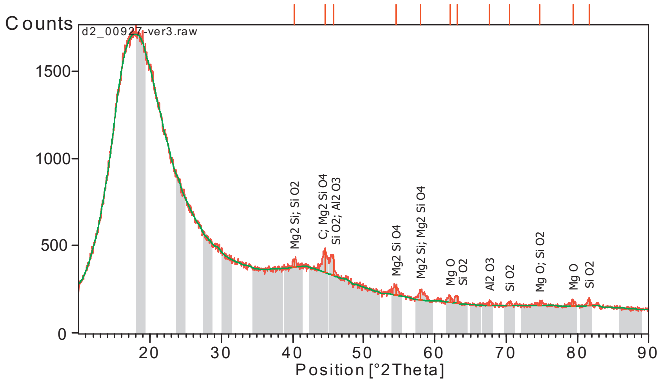

Fig. 4. XRD pattern of the coconut filler particle.

structure with linear boundaries between adjacent spherulites boundaries. From the EDS spectrum it can be clearly seen that the functional group of the epoxy was revealed, this is in line with the earlier research of Sreekanth et al. [1].

Fig. 7 shows the microstructure of the reinforced composite with coconut shell particle additions. The microstructure reveals that there are small discontinuities and a reasonably uniform distribution of coconut ash particles in the epoxy matrix. The ceramic phase is shown as white phase, while the polymer phase is dark (see Fig. 7). The coconut shell particles are embedded within the amorphous matrix composed of randomly distributed in the matrix planar boundaries. There was less pull of the coconut shell particles from the matrix, and there is evidence of improvement in the interfacial bonding between the coconut shell particles and the epoxy matrix.

Mechanical properties of the natural fillers composites depend on several factors such as the stress–strain behaviors of fillers and matrix phases, the phase volume fractions, the fillers concentration, the distribution and orientation of the fillers relative to one another. Figs. 8–10 show the typical tensile stress *vs.* strain curves for coconut shell filler composite, while the results of mechanical test is shown in Table 1. It can be seen that tensile strength and elastic moduli of the composites increase with an increase of the filler content. The composites demonstrate somewhat linear behavior and sharp fracture.

From the micro-hardness result for different weight percentages of coconut shell particle fillers, it is observed that with increase in filler content in the composite, its hardness value improves (see Table 1). Also an increase in tensile strength and tensile modulus

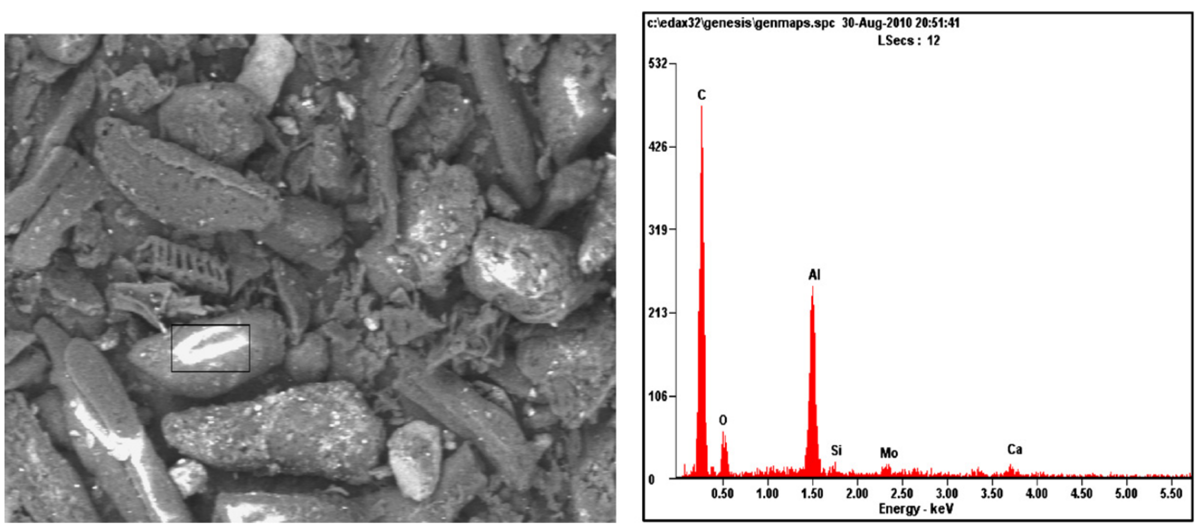

Fig. 5. SEM microstructure of the coconut shell particles (10,000×).

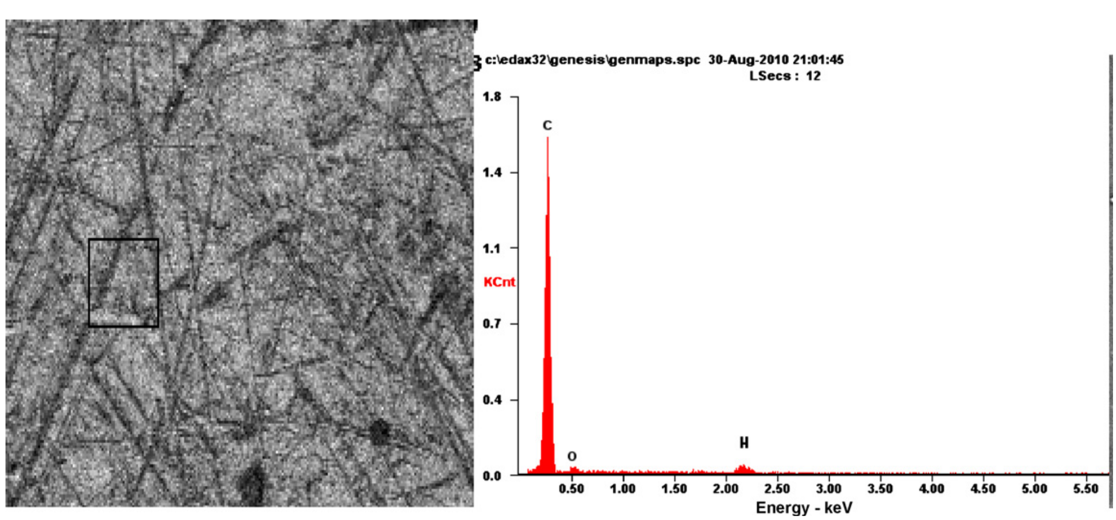

Fig. 6. SEM microstructure of the matrix epoxy (1000×).

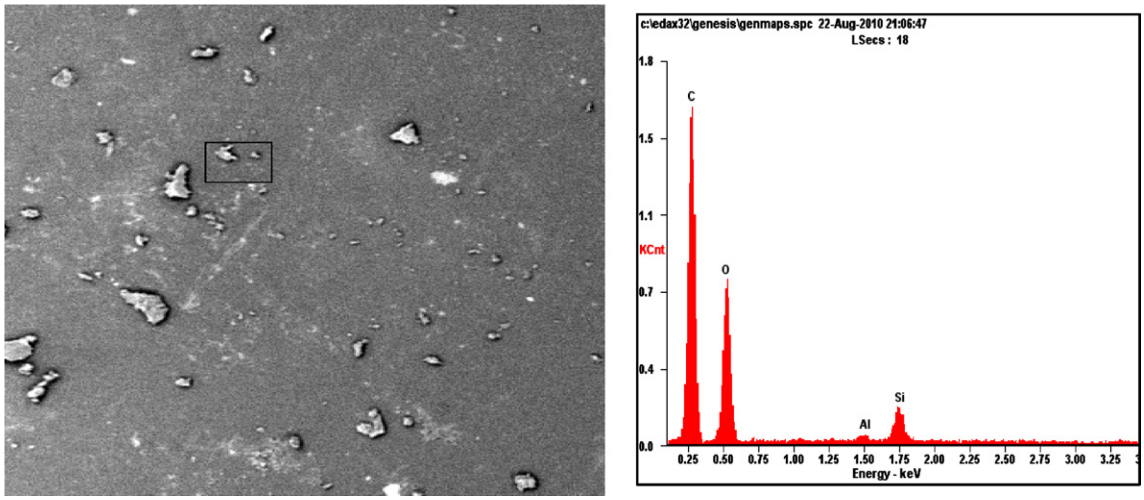

Fig. 7. SEM microstructure of the coconut shell fillers reinforced epoxy at 20 wt% (1000×).

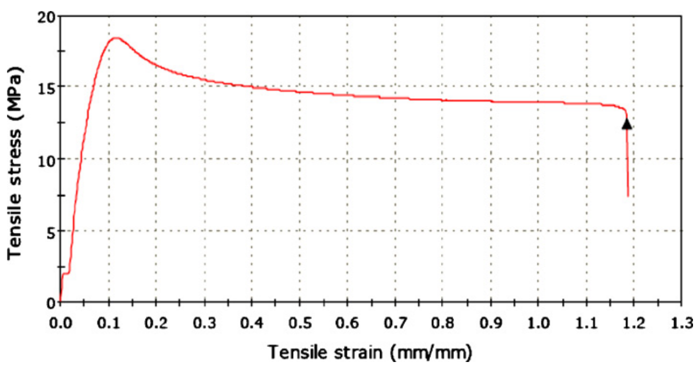

Fig. 8. Variation of tensile stress with tensile strain at 0 wt% coconut shell particle.

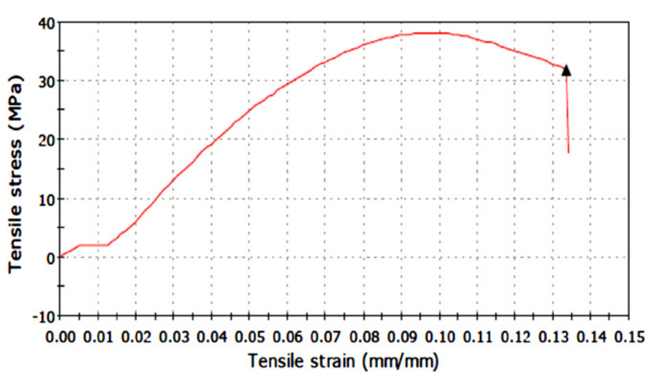

Fig. 9. Variation of tensile stress with tensile strain at 10 wt% coconut shell particle.

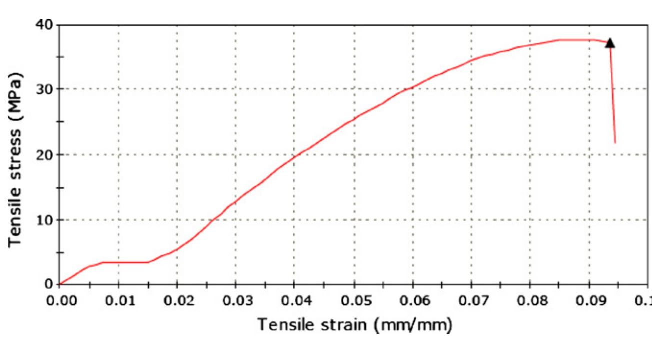

Fig. 10. Variation of tensile stress with tensile strain at 20 wt% coconut shell particle.

with the weight fraction of coconut shell fillers is noticed. It clearly indicates that addition of coconut shell particle filler improves the load bearing capacity of the composites. Similar observations have been reported by Sanadi et al. [10] for other fiber reinforced polymer composites. The increment in tensile strength and tensile modulus is due to the better-increased surface area of filler in the matrix (see Fig. 7). As the filler loading increased, thereby increasing the interfacial area, there was good interfacial bonding between the hydrophilic filler and the hydrophobic matrix polymer, which lead to, increased in the tensile strength [11].

Although the composite with 20 wt% coconut shell particles bears a higher load than other samples, resulting in a higher tensile strength (see Table 1). In addition, it deforms less until maximum load, which gives a higher tensile modulus. As a consequence, the tensile strength and the tensile modulus of the 20 wt% coconut shell particles composites show larger values due to the stability of the filler to support stresses transferred from the polymer matrix [11]. Similar results are reported in our previous paper for rice straw/polypropylene composite materials [7]. It may be mentioned here both tensile strength and tensile modulus are important for recommending any composite as a candidate for structural applications.

The energy absorbed at break of different weight percentages of coconut shell particle fillers is presented in Table 1. The energy at break or strain is expressed as the ratio of total deformation to the initial dimension of the material body in which the forces are being applied. It is observed that the energy at break was reduced a little bit due to addition of coconut shell fillers for every case which is because of increase of rigidity of material but considering the results the energy at break is a bit okay for this materials.

From Figs. 8–10, it is evident that the reinforced composites have lower area under the curves and therefore low energy at break values. This could be the predictable result, because rigid ceramics body such as coconut shell particles acts as barriers against the mobility of dislocations. Therefore, by increasing the content of coconut shell fillers, the rate of work hardening increases and this would lead to a decreased in the values of energy at break.

The impact strength of a composite is influenced by many factors, including the toughness properties of the reinforcement, the nature of interfacial region and frictional work involved in pulling out the fillers from the matrix. The nature of the interface region is extremely important and is directly related to the toughness of the composite [11]. The notched Charpy impact strength result is presented in Table 1. The Charpy impact test is a standardized high

Table 1
The mechanical properties of coconut shell particles reinforced epoxy composites.

% of coconut shell fillers	Young modulus (MPa)	Ultimate tensile strength (MPa)	Energy at break (J)	Impact energy (J)	Hardness values (HB)
0	320.84	18.43	16.37	1.00	4.1
10	683.56	31.82	11.24	0.75	7.8
20	688.14	37.31	9.59	0.70	9.5

strain-rate test, which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness and acts as a tool to study brittle–ductile transition. It is also observed that Charpy impact strength property was reduced a little bit due to addition of coconut shell fillers. This is mainly due to the reduction of elasticity [10] of material due to filler addition and there by reducing the deformability of matrix. An increase in concentration of filler reduces the ability of matrix to absorb energy and there by reducing the toughness. However the impact strength results obtained are within the recommended limit [12].

5. Conclusions

This study inspected the feasibility of utilizing of grain by-products such coconut shell as alternative fillers in polymer composites material. It can be concluded from the studies that the characterized composites showed improved tensile modulus, tensile strength and hardness values and very slight decrease of the impact strength, when compared to mechanical properties of pure epoxy resin. The obtained results of the developed composites have shown that the coconut shell waste could be used as alternative biodegradable eco-friendly reinforcement, but with further optimization of the conditions in order to obtain materials with improved mechanical properties.

References

[1] M.S. Sreekanth, V.A. Bambole, S. Mhaske, P.A. Mahanwar, J. Miner. Mater. Charact. Eng. 8 (3) (2009) 237–248.
[2] J.B. Zhong, J. Lv, C. Wei, Express Polym. Lett. 1 (10) (2007) 681–687.
[3] G. Hattotuwa, B. Premalal, H. Ismail, A. Baharin, Polym. Testing 21 (7) (2002) 833–839.
[4] H. Ismail, J.M. Nizam, H.P.S. AbdulKhalil, Polym. Testing 20 (2) (2001) 125–133.
[5] H. Ismail, M.R. Edyham, B. Wirjosentono, Polym. Testing 21 (2) (2002) 139–144.
[6] F. Mengeloglu, L.M. Matuana, J. Vinyl Addit. Technol. 9 (1) (2003) 26–31.
[7] H.-S. Yang, H.-J. Kim, J. Son, H.J. Park, B.J. Lee, T.S. Hwang, Compos. Struct. 63 (3) (2004) 305–312.
[8] F.P. La Mantia, M. Morreale, Z.A. Ishak, J. Appl. Polym. Sci. 96 (2005) 1906–1913.
[9] J. Sarki, Development and characterization of coconut shell particles reinforced epoxy composites, M.Sc. ongoing, Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria, Nigeria.
[10] A.R. Sanadi, D.F. Caulfield, R.M. Rowell, Plast. Eng. 4 (1994) 27–30.
[11] B.F. Abu-Sharkh, R. Kahraman, S.H. Abbasi, I.A. Hussein, J. Appl. Polym. Sci. 92 (2004) 2581–2592.
[12] X.Y. Chen, Q.P. Guo, X.L. Mi, J. Appl. Polym. Sci. 69 (1998) 1891–1895.