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STUDY OF MECHANICAL PROPERTIES OF CARBONIZED COCONUT SHELL POLYESTER COMPOSITE

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ABSTRACT

This study investigated the effects of carbonized coconut shell (CS) volume fractions on mechanical properties of unsaturated polyester resin (UPR) composite. The coconut shell was carbonized at 700^{o}C with a soaking time of three hours. Two different particle sizes of 1.70mm (referred to as coarse particle) and 425microns (referred to as fine particle) of carbonized coconut shell were used. Varying percentages of the coconut shell (10, 20 and 30) were used as reinforcement in the unsaturated polyester resin to form composites and the mechanical properties like tensile strength and flexural strength of the composites examined. 1g and o.5g of catalyst and accelerator were added respectively to the composite mixture. The flexural strength was determined using the TUE-C- 100 Model of universal testing machine, the tensile test was performed using INSTRON 1195 testing machine.The chemical analysis was done using Mini Pal compact energy dispersive X-ray spectrometer (XRF). The results obtained showed that elongation at break and flexural strength increased as coconut shell concentration increased. The maximum flexural strength of the composites was found to possess153 % improvement over the virgin unsaturated polyester resin. Though, the tensile strength of the composite increased with increase in coconut shell concentration, however, it was less than that of the virgin unsaturated polyester resin. Optimum results of better filler/matrix interaction were mainly obtained at 20% volume fraction of reinforcement.

Keywords: Carbonized, Coconut shell, Composite, Polyester.

1. 1 INTRODUCTION

The interest in natural particle-reinforced polymer composite materials is rapidly growing both in terms of their industrial applications and fundamental research. They are renewable, cheap, completely or partially recyclable, and biodegradable (Singh, et al, 2013).

Plants, such as flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie, bamboo, banana, etc., as well as wood, used from time immemorial as a source of lingo-cellulosic particles, are more and more often applied as the reinforcement of composites. Their availability, renewability, low density, and price as well as satisfactory mechanical properties make them an attractive

ecological alternative to glass, carbon and man-made particles used for the manufacturing of composites.

As was observed by Prakash, (2009), natural particle-containing composites are more environmentally friendly, and are used in transportation (automobiles, railway coaches, aerospace), military applications, building and construction industries (ceiling paneling, partition boards), packaging, consumer products, etc.

Coconut shells are available in abundance in tropical countries as a waste product after consumption of coconut water and meat. Such abundance can fulfill the demand of filler based composites while reducing waste. Procurement and processing of coconut shell powder is cost effective than other artificial fillers. Previously, coconut shell was burnt as a means of solid waste disposal which contributed significantly to CO_2 and methane emissions (Singh, et al, 2013).

A pressing issue in Nigeria today, is the recycling of waste products and other agricultural by-products suitable for the invention and characterization of new materials (Agunsoye et al, 2012).

In their separate works, Monteiro et al, (2008) and Wang and Huang, (2009), stated that annually, approximately 33 billion coconuts are harvested worldwide with only 15% of these coconuts being utilized for fibers and chips. This suggests that there is considerable room to reduce this kind of environmental pollution and enhance the efficiency of using natural resources.

Coconut shells are cheap and readily available in high quantity. Coconut shell contains about 65 – 75% volatile matter and moisture which are removed largely during the carbonization process (Chanap, 2012). The carbonization process involves converting the coconut shells to char (charcoal). The charring process (making of charcoal) is known as the pyrolysis, which is chemical decomposition of the shell by heating in the absence of oxygen. During the carbonization of coconut shells, volatiles amounting to 70% of the mass of coconut shells on dry weight basis are released to the atmosphere, yielding 30% of coconut shell mass of charcoal. The volatile released during the carbonization process is methane, CO_2 and wide range of organic vapors. The carbonization temperature ranges between 400^oC and 850^oC sometimes reaches 1000^oC.

Schröder et al, (2011) produced charcoal from different waste biomass including coconut shell. They generated activated carbon in a two-step process of pyrolysis at 600°C and steam activation at 900°C.

Jun et al, (2011), concluded that surface modification of coconut fiber by plasma treatment to enhance the interfacial adhesion between the coconut fibers and poly lactic acid (PLA) matrix improves the mechanical properties, such as tensile strength and Young's modulus of a coconut fibers/PLA green composites fabricated using commingled yarn method. Han-Seung Yang et al, (2004), reported that the tensile strengths of the bio composites decrease slightly as the filler loading increased, however the composites retained an acceptable level of strength.

Husseinsyah and Mostapha, (2011), were of the view that increase in coconut shell content increases the tensile strength, Young's modulus and water absorption rate but reduces the elongation at break of coconut shell filled polyester composites.
Andrzej and Abdullah, (2010), observed that coconut shell reinforced composites showed 80% better elongation at break and 20% better Charpy impact strength than soft wood composites. With its natural waxy surface layer, coconut fiber according to Brahmakumar, (2005), provides a strong interfacial bonding between the fiber and polyethylene matrix.
In this work, an attempt is made to use the agro-based coconut shell particles in carbonized form as a reinforcement material in polyester matrix with the aim to improve the mechanical properties.

2.0 Materials and methods

2.1 Materials

Materials used in this experimental work were coconut shell bought from Ogbete main market in Enugu; unsaturated polyester resin (matrix), methyl ethyl ketone peroxide (catalyst), cobalt Naphthanate (accelerator) were supplied by Ndidiamaka Trading Company in Enugu.

2.2 Methods.

2.2.1 Coconut shell processing (Carbonization)

The coconut shell was sun dried for 48 hours. It was later packed in an earthen, covered with a lid and heated in electric resistance furnace at temperature of about 700^{o}C at a heating rate of 5^{o}C per minute with a soaking time of three hours to form carbonized coconut shell. This was crushed to powder using a pulverizing machine. A particle size analyzer in accordance with ASTM standard was used to obtain two filler sizes of 425 μm and 1.70mm.

2.2.2 Composites sample preparation

A mold of 420 mm × 20 mm × 15 mm having a glass base and sides of wood was used for casting the composite sheets. For quick and easy removal of the composite sheet a mold release sheet was kept over the glass plate and wood sides. Weight percents of carbonized coconut shell powder (i.e. 0, 10, 20 and 30 weight %), were mixed with the matrix material consisting of polyester resin, accelerator and catalyst. The accelerator and the catalyst were mixed in the ratio of 1:2. Care was taken to avoid formation of air bubbles during pouring and the mixture was covered to avoid buckling and allowed to cure at room temperature for 24 hours. After curing, the laminate produced was trimmed and cut into required sizes for various mechanical tests.

2.3 Testing of mechanical properties of composites

Mechanical properties such as tensile strength and flexural strength of carbonized coconut shell powder reinforced polyester (randomly distributed in polyester matrix) composite have been conducted as per ASTM D790 for flexural strength, ASTM D785 standard for hardness and ASTM D638 for tensile strength. The test specimen dimensions are as follows:

Flexural test specimen: 110mm x 40 mm x 10mm
Tensile test specimen: 400mmx20mmx7mm

2.3.1. Tensile Strength

The tensile test was carried out on the material to determine its strength and ductility. The tensile test was performed in INSTRON 1195 testing machine. This test was conducted by loading the specimen into a universal testing machine that can apply a load to the specimen at a specific rate. The specimen was axially loaded in tension; the distance between the gauge marks was monitored. The specimen was elongated by the moving crosshead, load cell and extensometer measured the magnitude of the load and the elongation. Three samples each per volume fraction of coconut shell were tested and the average value taken.

$UTS = UTL/A\ (N/mm^2)$ ..... (2)

Where, UTS - ultimate tensile strength
UTL – Ultimate tensile load
A – Cross-sectional area of the specimen (mm^2)

2.3.2. Flexural Test Procedure

Flexural test was performed using Universal Testing Machine model TUE-C-100, according to ASTM D790.The composite samples were tested at a cross head speed of 5 mm/min. In each case, three samples were taken and average value was recorded.
The flexural stress in the developed composite was calculated using the formular:

$\sigma max = \frac{3P_{max}\ L}{bh^2}$ ..... (3)

Where, P_{max} is the maximum load at failure (KN), L is the span (mm); b and h are the width and thickness of the specimen (mm) respectively.

3.0 Results and Discussions

Table 3.1: XRF Oxides of elements test result

Oxides of Element	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	SiO_2	MnO	ZnO
%	15.48	0.67	14.4	0.49	17.02	0.65	43.11	0.52	0.37

3.1. Ultimate Tensile Strength

Table 3.2: Ultimate Tensile test result

Volume fraction of particulate %	Designation of Sample	Ultimate tensile strength MPa	Tensile Strain %	Designation of Sample	Ultimate tensile strength MPa	Tensile Strain %

0%	Control	18.58	0.62	Control	18.58	0.62
10%	CFS	9.48	0.38	CCS	9.91	0.30
20%	CFS	10.88	0.17	CCS	9.96	0.26
30%	CFS	8.22	1.65	CCS	6.13	0.46

KEY
CFS: Carbonized Fine Sample
CCS: Carbonized Coarse Sample

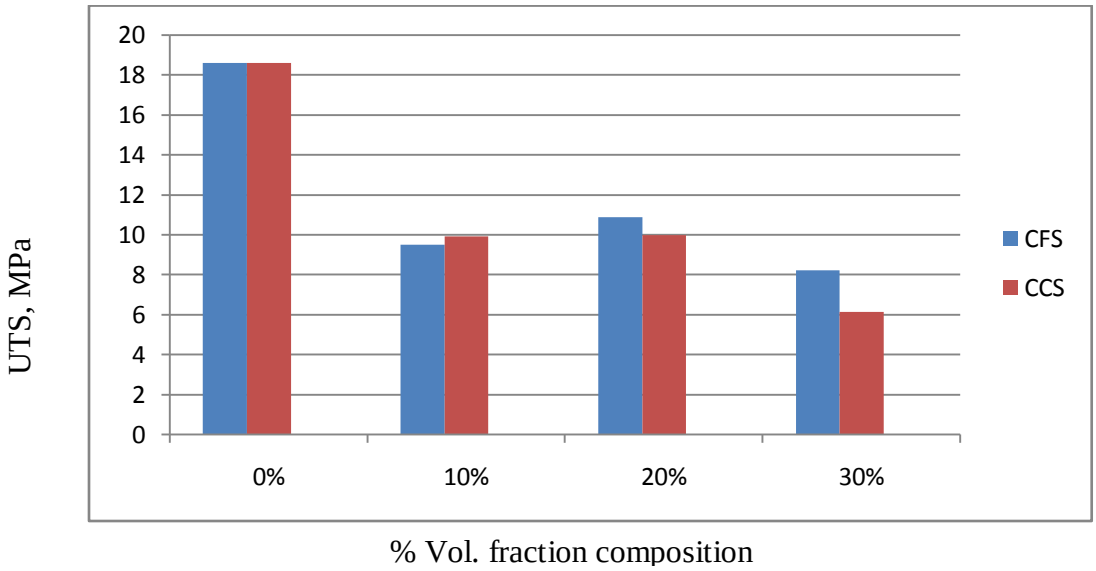

Figure 3.1: Effects of carbonized fine and coarse particles coconut shell on tensile strength of coconut shell particle reinforced unsaturated polyester composite.

The tensile strength values of the composites increased with increase in the volume percent fraction of the coconut shell particles within the matrix of the composite. The tensile strength increased with increase in filler content reaching a maximum tensile strength value of 10.88MPa for the carbonized fine coconut shell particle reinforced sample at 20wt% volume fraction but declined on further filler addition. This agrees with the findings of (Teipel, 2011) where CS addition produced an initial increase in tensile strength of the composites up till 40 % of CS before it declined with further addition of CS as was reported in (Adeosun et al, 2015), Thermo-Mechanical Properties of Unsaturated Polyester Reinforced with Coconut and Snail Shells. Similarly, (Husseinsyah and Mostapha, 2011), showed that tensile strength of Polyester/CS composites increased with increase in weight fraction of CS after an initial drop with 15 php. The lignin content in coconut shell particles consist of polar hydroxyl groups, benzene rings and non-polar hydrocarbon which is capable of enhancing the adhesion between the reinforcement and the matrix as was observed by (Salmah et al, 2013) in Treated Coconut Shell Reinforced Unsaturated Polyester Composites. In addition, increase in tensile strength could equally be attributed to increase in surface area, good distribution and dispersion of the reinforcement in the

matrix and this is in line with the work of (Durowaye et al, 2014) and **(**Singh et al, 2013) in their works Mechanical Properties of Particulate Coconut Shell and Palm Fruit Polyester Composites and Study of mechanical properties and absorption behavior of coconut shell powder-epoxy composites respectively. This results into strong particles–matrix interaction which increases the ability of the particles to restrain gross deformation of the matrix.

The lowest tensile strength value of 6.13MPa in the carbonized samples was recorded in the 30wt% coarse particle reinforced sample which could be due to poor distribution of the reinforcement within the matrix and poor interfacial bonding between the matrix and the filler coconut shell particles.

3.2. Flexural test result

Table 3.3: Flexural test result

Volume fraction of particulate	Sample Designation	Flexural force	Flexural Strength	Sample Designation	Flexural force	Flexural Strength
0%	Control	2.148	39.371	Control	2.148	39.371
10%	CFS	4.110	75.350	CCS	2.470	45.280
20%	CFS	5.440	99.733	CCS	0.615	11.275
30%	CFS	4.015	73.610	CCS	2.240	41.070

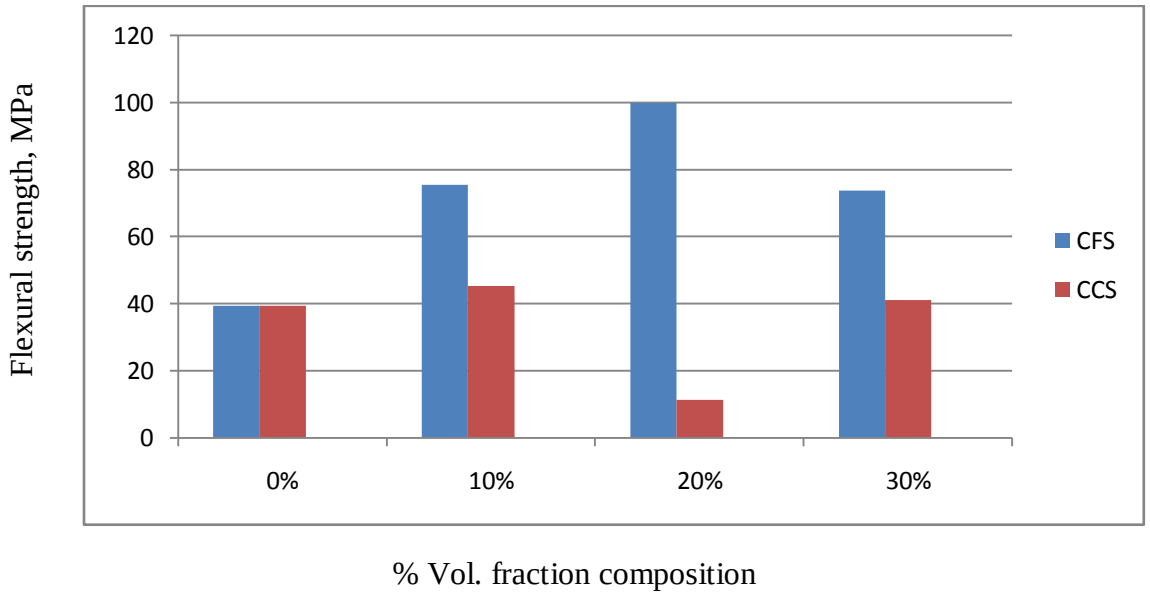

Figure 3.2: Effects of carbonized fine and coarse particles coconut shell on flexural strength of coconut shell reinforced unsaturated polyester composite.

The flexural strength of the composites generally increased with increase in reinforcement content at 10 % volume fraction compared with the virgin unsaturated polyester resin. This increase could possibly be due to the strong interfacial adhesion between the particles and the matrix which enhances load transfer as was indicated by (Swain, 2013). The 20% volume fraction carbonized fine particle reinforced sample had a higher increase in flexural strength (153%) than any other sample and exhibited the maximum flexural strength of 99.733MPa. This may be as a result of carbonization which enhanced the structural strength of the coconut shell particle to withstand excessive particle crumble during use (Manocha, 2003). (Sapuan and Harimi , 2003), in their work Mechanical Properties of Epoxy/Coconut shell Filler Particle Composites examined the flexural properties of epoxy - CS composites and reported an increase in flexural strength and modulus up to 15 wt. % CS within the weight fractions considered. Also, the later decrease in flexural strength as the volume fraction of the filler coconut shell increased as observed in the 30wt% volume fraction is due to agglomerate formation at higher concentrations of the reinforcement. The low flexural strength of the coarse particle reinforced composite is due to reduced surface area of the reinforcements in the matrix.

4. Conclusion

Carbonization of coconut shell at 700^{o}C has enhanced the mechanical properties of coconut shell reinforced polyester composite. The fine particle reinforced coconut shell reinforced composite had a better flexural strength and tensile strength compared to the coarse particle carbonized coconut shell reinforced polyester composite. To obtain maximum flexural and tensile strengths using carbonized coconut shell, the coconut shell should be in powdered form and at a volume fraction of 20wt. %. In this study therefore, carbonized coconut shell particles enhanced the mechanical properties of polyester matrix composites and are a potential material for automobile application requiring moderate strength.

5.0 Recommendation

It is recommended that further work should be carried out in the area of adding a coupling agent to the composite mixture during the preparation/formulation period.

Reference

Alok S., Savita S., Aditya K. (2013). Study of Mechanical Properties and Absorption Behaviour of Coconut Shell Powder-Epoxy Composites. *International Journal of Materials Science and Applications.* Vol. 2, No. 5, 2013, pp. 157-161. doi: 10.11648/j.ijmsa.20130205.12.

Prakash T. (2009). Processing and Characterization of Natural Fiber Reinforced Polymer Composites. Bachelor's Thesis, National Institute of Technology, Rourkela.

Elisabeth S., Klaus T., Benjamin O., Sabrina H., Sabine B and Andreas H. (2011). Activated Carbon from Waste Biomass, Progress in Biomass and Bioenergy Production.

Han-Seung Y., Hyun-Joong K., Jungil S., Hee-Jun P., Bum-Jae L., Taek-Sung H. (2004). Rice-husk flour filled polypropylene composites; mechanical and morphological study. Elsevier Composite Structures 63 pp. 305–312.

Rahul C. (2012). Study of Mechanical and Flexural Properties of Coconut Shell Ash Reinforced Epoxy Composites', Mechanical Engineering Department National Institute of Technology Rourkela.

Husseinsyah S. and Mostapha M. (2011). The effect of Filler Content on Properties of Coconut Shell Filled Polyester Composites. *Malasian Polymer Journal*, Vol. 6, No. 1, pp. 87-97.

Durowaye S. I., Lawal G.I., Akande M.A.,Durowaye V.O. (2014). Mechanical Properties of Particulate Coconut Shell and Palm Fruit Polyester Composites. International Journal of Materials Engineering 4(4): pp.141-147.

Salmah, H., Marliza, M., Teh, P.L. (2013). Treated Coconut Shell Reinforced Unsaturated Polyester Composites. International Journal of Engineering & Sciences.http://www.ijens.org/Vol_13_I_02/1310202-8383-IJET-IJENS.pdf.

Agunsoye J. Olumuyiwa, Talabi S. Issac, Sanni O, Samaual (2012). Study of mechanical behavior of Coconut Shell reinforced Polymer matrix composites. Journal of minerals and materials characterization and Engineering, pp.774-779.

Monteiro S. N., Terrones, L. A. H., D'Almeida J. R. M. (2008). Mechanical Performance of Coir Fiber/Polyester Composites. *Polymer Testing*, Vol. 27, No. 5, pp. 591- 595. doi:10.1016/j.Polymertesting.2008.03.003 .

Wang W., Huang, G. (2009). Characterization and Utilization of Natural Coconut Fibers Composites. *Materials & Design*, Vol. 30, No. 7, pp. 2741-2744.

Jun, Y. J., Tae, K. J., Hwa, J. O., Jae R. Y., Young, S. S. (2011). Thermal Stability and Flammability of Coconut Fiber Reinforced Poly (Lactic Acid) Composites. *Composites Part B*: *Engineering*, Vol. 43, No. 5, pp. 2434-2438.

Andrzej, K., Abdullah, A. (2010). Barley Husk and Coconut Shell Reinforced Polypropylene Composites: The Effect of Fiber Physical, Chemical and Surface Properties. *Composites Science and Technology*, Vol. 70, No. 5, pp. 840-846.

Brahmakumar, M., Pavithran, C., Pillai, R. M. (2005). Coconut Fiber Reinforced Polyethylene Composites: Effect of Natural Waxy Surface Layer of the Fiber on Fiber/Matrix Interfacial Bonding and Strength of Composites. *Composites Science and Technology*, Vol. 65, No. 3-4, pp. 563-569.

Ali I. A., Dr. Mustafa A. R., Nawal, A., Saleh M. (2013). Flexural Strength of Fiber Reinforced Composite. International Journal of Enhanced Research in Science Technology & Engineering, Vol.2 Iss.1.

Teipel E.G. (2011). Polymeric Composites Reinforced with CSP: Coconut Shell Powder Technology, Young Persons' World Lecture Competition (YPWLC).

Adeosun1, S. O., Akpan, E. I., Akanegbu, H. A. (2015). Thermo-Mechanical Properties of Unsaturated Polyester Reinforced with Coconut and Snail Shells. International Journal of Composite Materials Vol. 5(3): pp. 52-64

Manocha S. (2003). Porous carbons. Sadhana. Vol. 28 (1 & 2), pp. 335–348.

Sapuan, S.M., Harimi, M., Maleque, M. A. (2003). Mechanical Properties of Epoxy/Coconut shell Filler Particle Composites. The Arabian Journal for Science and Engineering, Volume 28, Number 2B.