EUROPEAN JOURNAL OF MATERIALS SCIENCE AND ENGINEERING
Volume 4, Issue 4, 2019: 212-220 | www.ejmse.tuiasi.ro | ISSN: 2537-4338

EJMSE

DOI: 10.36868/ejmse.2019.04.04.212

INFLUENCE OF THE VARIATION OF PARTICLE SIZE AND CONTENT ON THE MECHANICAL PROPERTIES OF COCONUT HUSK ASH (CHA)-REINFORCED POLYESTER COMPOSITE

Tertsegha Daniel IPILAKYAA[1,*], Livinus Tyovenda TULEUN[1], James Terngu SULE[1]

[1]Department of Mechanical Engineering, University of Agriculture Makurdi, Benue State, Nigeria

Abstract

The influence of the variation of particle size and content on the mechanical properties of polyester when reinforced with coconut husk ash (CHA) have been studied. Clean and pretreated coconut husk was burnt in open air and ash particles were obtained using 75, 150 and 300 µm British standard sieves. Unsaturated polyester resin (matrix) was used to produce polymer composite by hand lay-up technique with 5, 10, 15, 20 and 25 percent by weight CHA particles. Three samples per particle size per percent by weight of CHA were used to perform tensile, flexural, impact and hardness tests according to ASTM standards, and their average values obtained. The results show that, for each particle size, the impact energy of the composite increased to maximum values of 0.37 KJ/m^2, 0.58 KJ/m^2 and 0.38 KJ/m^2 respectively for 75, 150 and 300 µm, with progressive addition of CHA particles; respective values for 75 µm, 150µm and 300µm particle size reinforcement of other properties generally increased to maximum values of 17.72 MPa, 28.61 MPa and 20.00 MPa for tensile strength, 12.6 HRF, 11.3 HRF and 10.5 HRF for hardness, 21.7 MPa, 38.57 MPa and 37.00 MPa for modulus of rupture and 599.17 MPa, 909.95 MPa and 947.12 MPa for modulus of elasticity, but decreased thereafter with 150µm particle size presenting better properties.

Keywords: *coconut husk ash, unsaturated polyester resin, polymer composite, particle size.*

Introduction

Composites are materials with many functional systems that provide properties not obtainable from any monolithic material; they are bonded structures made by physically combining two or more friendly materials which differ in properties and behaviour, and sometimes even in form; the two main components are matrix and reinforcement (or more broadly dispersed phase). The matrix, known also as continuous phase, integrates reinforcement particles, shapes products correctly and also determines most physical and chemical properties of the material. The ability of composites to be tailored for a specific purpose has been one of their greatest advantages [1].

According to the type of matrix, composites are classified into Metal Matrix Composites (MMCs), Ceramic Matrix Composites (CMCs) and Polymer Matrix Composites (PMCs). The matrix phase of commercial PMCs can be classified as either “thermoplastic” or “thermoset.”

Reinforcements used in composites can be classified into four basic types: continuous fibres, discontinuous fibres, whiskers (elongated single crystals), and particles. Continuous aligned fibres are the most effective reinforcement form and are mostly used in high-performance applications. However, for ease of construction and to accomplish specific properties, such as improved through-thickness strength, continuous fibres are altered into other reinforcement types such as the particle type.

Corresponding author: ipilakyaa@yahoo.com, +234-8063070213

Composites reinforced with bio-products have received attention because of their biodegradability, lightweight, abundance, cost effectiveness, non-toxicity, relative strength, renewability and their consideration to be virtuous products; they also have good formability, thermal insulation properties and acoustic properties [2]. Biodegradable materials such as the shells of different dry fruits, rice husk, wheat husk, straws and hemp fiber have been used to prepare fiber and particle reinforced polymer composite [3-6].

The properties of polymer composites made with plant materials depends largely on constituent's interphase reactions. The right share of the reinforcement in the matrix is also considered important. Usually, it is essential to use procedures or additives that improve harmony of composite components [7]. The most universally used procedures include chemical alteration, for example, pretreatment with sodium hydroxide, mixture of fibers with matrix friendly polymer, graft copolymerization, acetylation, mercerization or physical alteration, e.g. corona discharge, thermal and plasma treatment [8]. Such alterations other than improved bonding, are generally meant to limit water suction, increase in dimensional stability and its resistance to environmental factors [7].

The polymeric structure of Coconut husk is made up of cellulose (28%), hemicellulose (38%) and lignin (32.8%) [9]. Dried husk of a well developed coconut fruit is said to be in the range of 200 to 400g (Ding, 2014). Ding *et al* [10] reports that according to FAO, annual production from the top ten coconut producing countries was approximately 54 million tonnes by 2008. Despite the hug availability, not much of this bio-product is utilized hence constituting environmental concern. The present study is intended to develop a polymer composite using coconut husk ash.

Materials and Methods

Coconut husks were sourced within Makurdi, Benue State, Nigeria. Unsaturated Polyester Resin (matrix material), Methyl Ethyl Ketone Peroxide (catalyst) and Cobalt Naphthanate which act as an accelerator were also procured from the Chemical Market in Lagos, Nigeria. The following equipment were used for the tests: Electronic weighing machine, laboratory sieves (JINLING BS40 Series SHANG CHINA), Monsanto Tensometer testing machine Type "W", Charpy Impact Testing Machine Avery Denison, Universal Materials Testing Machine ENERPAC.

Preparation of reinforcement material

Coconut Husk Ash was used as the reinforcement material. Dry coconut husks were soaked in clean water for 48 hours to soften them, after which they were retted to coconut husk fibres. The retted fibres were thoroughly washed in clean water to remove dirts; they were dried and thereafter pretreated. Chemical pretrearment of the coconut husk fibres was achieved by soaking the dried coconut husk fibres in a solution of sodium hydroxide (NaOH) for 24 hours [11]. The fibers were removed and washed thorougly with clean water; they were dried and burnt with sufficient supply of oxygen (in open air) to obtain the ash particles. Three particle sizes (75µm, 150 µm and 300µm) were charaterised from the ash using standard laboratory seives.

Composite materials formulation

The weight percentages of the matrix (Unsaturated Polyester Resin) and reinforcement (Coconut Husk Ash) were weighed into a mixing container as required by the values in Table 1, and stirred continously at room temperature for about three minutes until a homogenous mix was observed; the same procedure was repeated for other matrix and reinforcement amounts needed for the other particulate mixtures. Each mixture was placed on an electronic weighing machine and the catalyst (Methyl Ethyl Ketone Peroxide, MEKP) was added in drops until the required weight was obtained (1% wt. of UPR); the mixture was then stirred thoroughly for another three minutes. Thereafter, the accelerator (Cobalt Naphthanate) was also added to the required weight (0.5% wt of UPR) [12].

Table 1. Composite materials formulation

Materials	Particle size	Weight percentage (wt %)				
		5	**10**	**15**	**20**	**25**
Coconut husk ash	75 microns	5	10	15	20	25
Polyester resin		95	90	85	80	75
Coconut husk ash	150 microns	5	10	15	20	25
Polyester resin		95	90	85	80	75
Coconut husk ash	300 microns	5	10	15	20	25
Polyester resin		95	90	85	80	75

Composite production

Manual mixing in plastic container and hand lay-up technique were used for the composite production. The composites were prepared using 5%, 10%, 15%, 20%, and 25%, reinforcement of coconut husk ash for each particle size.

A spirit level was used to check the level of the table upon which the wooden moulds were to be placed. The mixtures, obtained as explained above, were gently poured into the wooden mould which had been coated with paraffin wax (as a releasing agent) to ease the removal after curing. While pouring the mixture, the mould was gently shaken continuously so that the mixture spreads evenly. The ceiling fans were switched off to prevent bubble formation. The casts were allowed to cure, at room temperature. The cured plates were removed from the mould and the overflown flakes were cut off. Finally, the composite plates were cut into different dimensions for mechanical and physical property tests.

Mechanical Properties Test

Generally acceptable standard test procedures were used to determine the mechanical properties of composite samples. The Tensile test was performed according to ASTM D638 [13], with specimen dimensions of 100 x 10 x 5mm and guage length of 40mm at a cross head speed of 5mm/min. Flexural test was performed according to ASTM D790-03 [14], with specimen dimensions of 100 x 30 x 5mm. Charpy impact test was performed according to ASTM D-256 [15], with notched specimen that had dimensions of 80 x 10 x 10mm. Hardness test was undertaken using Rockwell hardness test method on scale F with a 1.56 mm steel ball under a minor load of 3 kg and a major load of 60 kg.

Tensile strength

The tensile strength values of coconut husk ash particles reinforced polyester composite specimens are shown in Table 2 and Figure 1. Sample results for 75µm showed that tensile strength increased up to 15% reinforcement (which showed the highest tensile strength value for this particle size), decreased at 20% and then increased slightly at 25%. A similar trend was also observed for the other particle sizes: 150µm particle composite had a maximum tensile strength of 28.61MPa at 10% reinforcement while 300µm particle composite had a maximum tensile strength of 20.00MPa at 10% reinforcement. From the test results for the particle sizes, it was observed that better tensile strength value for 75µm was obtained at a maximum reinforcement of 15% while that of 150µm and 300µm was obtained at a maximum reinforcement of 10%. Generally, the 150µm gave the best overall tensile strength of 28.61 MPa for the 10% reinforcement of coconut husk ash. The decrease in tensile strength at higher weight fraction of particles in the composites could be attributed to uneven dispersion or agglomeration of particles leading to poor load transfer ability.

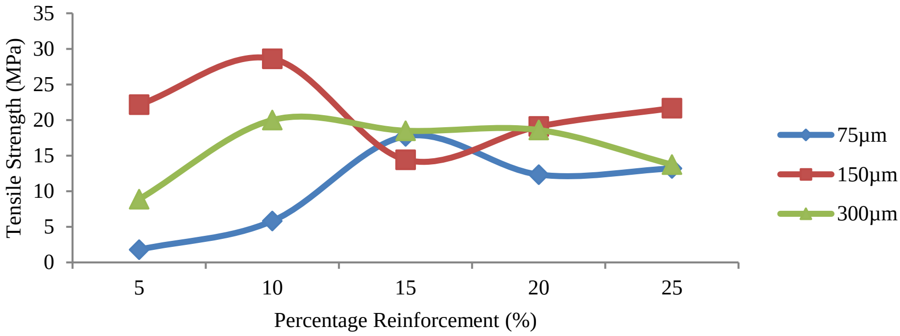

Fig. 1. Effect of reinforcement on tensile strength of coconut husk ash reinforced composite

Similar results have been reported by Durowaye *et al.*, [12] who said that the initial continuous increase in the tensile strength of coconut shell and palm fruit composites was due to the increase in surface area, good distribution and dispersion of the reinforcement in the matrix, while the its decrease after reaching a maximum was likely because of discontinuity between the particles surface and the matrix as the reinforcement concentration increased in the two composites.

Table 2. Results of mechanical properties test

Particle size (µm)	Weight fraction of part. (%)	Tensile strength (MPa)	Young's Modulus (MPa)	Percent Elongation (%)	Impact strength (KJ/m^2)	Rockwell Hardness (HRF)	Modulus of Rupture (MPa)	Modulus of Elasticity (MPa)
	5	1.80	7.06	25.5	0.13	4.3	4.61	215.31
	10	5.82	23.95	24.3	0.20	6.2	13.33	411.67
75	15	17.72	88.83	22.2	0.30	9.3	17.79	599.17
	20	12.34	50.99	24.2	0.35	8.7	18.89	427.87
	25	13.20	45.99	28.7	0.37	12.6	21.97	344.64
	5	22.16	87.94	25.2	0.23	9.5	22.90	519.00
	10	28.61	100.74	28.4	0.25	10.0	38.57	909.95
150	15	14.43	45.96	31.4	0.25	11.3	22.18	345.02
	20	19.10	66.34	28.8	0.28	10.0	31.91	743.94
	25	21.67	66.27	32.7	0.58	9.4	37.69	894.00
	5	8.88	51.03	17.4	0.30	7.1	24.67	517.84
	10	20.00	88.89	22.5	0.32	8.6	30.86	927.12
300	15	18.50	72.55	22.5	0.32	10.5	27.07	794.79
	20	18.60	76.54	24.3	0.36	8.1	37.00	947.12
	25	13.74	50.15	27.4	0.36	7.8	26.94	740.97

B Young's modulus

The result of Young's modulus of coconut husk particle reinforced polyester composite is shown in Table 2 and Figure 2. The Young's modulus of all the particle sizes increased as the reinforcement increased to a maximum and then decreased steadily: the composite made from the 75µm particles increased to a maximum of 88.83MPa at the 15% weight reinforcement before the steady decrease, composite from 150 µm particles increased to a maximum of 100.74MPa at 10% weight reinforcement before steady decrease, and the composites from 300 µm particles increased to a maximum of 88.89MPa before the decrease. 10% reinforcement of 150µm gave the highest value of Young's modulus (100.74MPa) than percent reinforcements of all other particle sizes.

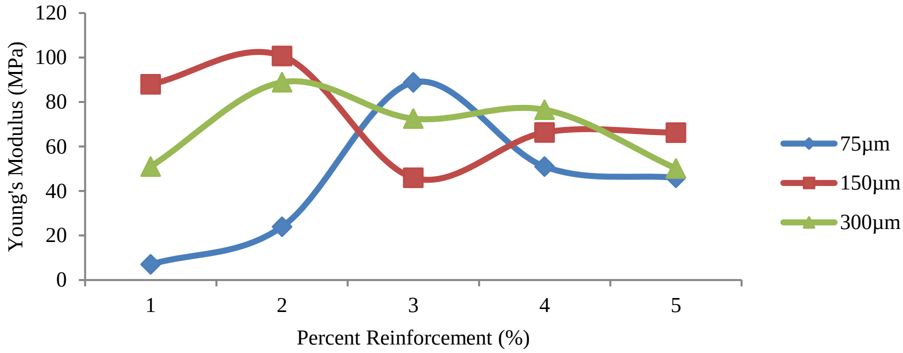

Fig. 2. Effect of reinforcement on Young's modulus of coconut husk ash reinforced composite

The Young's modulus property behaviour of CHA composite of different particle sizes (that is, initial increase to a maximum and then steady decrease) may possibly lead to the conclusion that its Young's modulus depends on the interficial interaction between particles much more than it depends on the weight percentage of particles [16].

Percent elongation at fracture

The result of the percent elongation at fraction is shown in Table 2 and Figure 3. The result showed that the percent elongation of the coconut husk ash reinforced polyester composite increased with increase in reinforcement for the particle sizes, although 75µm showed initial decrease from 25.5% elongation at fracture before eventually increasing to a maximum of 28.7%. 150µm particle size reinforced composite increased to a maximum of 32.7% elongation at fracture at 25% reinforcement. 300µm increased from 17.4% elongation at fracture to a maximum of 27.4%. The percent elongation at fracture of all particle sizes increased with increase in weight percent; however, there was decrease as the particle size increased. 150 µm had the maximum value of percent elongation at fracture at 25% reinforcement.

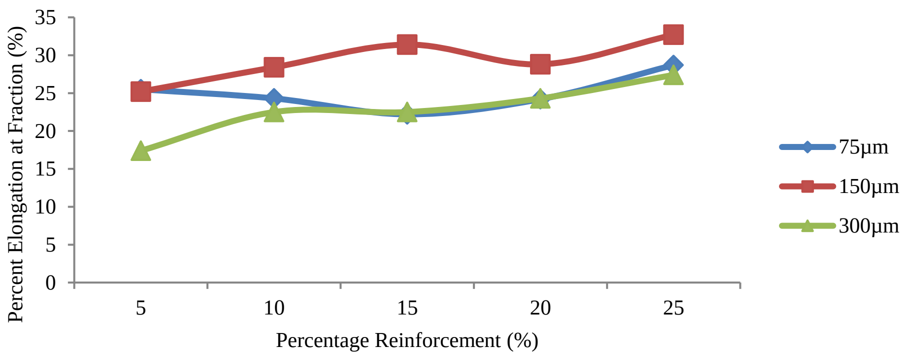

Fig. 3. Effect of reinforcement on percent elongation of coconut husk ash reinforced composite

Flexural test

The results of modulus of rupture(MOR) and modulus of elasticity (MOE) are as shown in Table 1, and Figure 4 and 5. The results reveal that for 75µm ash particle composite, the modulus of rupture increased from 4.61MPa to a maximum value of 21.97MPa; and the modulus of elasticity for this particle size increases to a maximum value of 599.17MPa at 15% reinforcement before decreasing to 344.64MPa at 25% reinforcement.

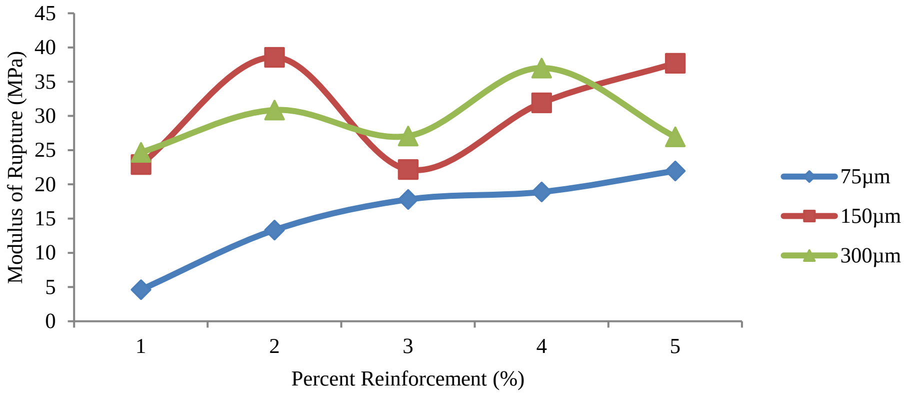

Fig. 4. Effect of reinforcement on Modulus of Rupture of Coconut Husk Ash reinforced composite

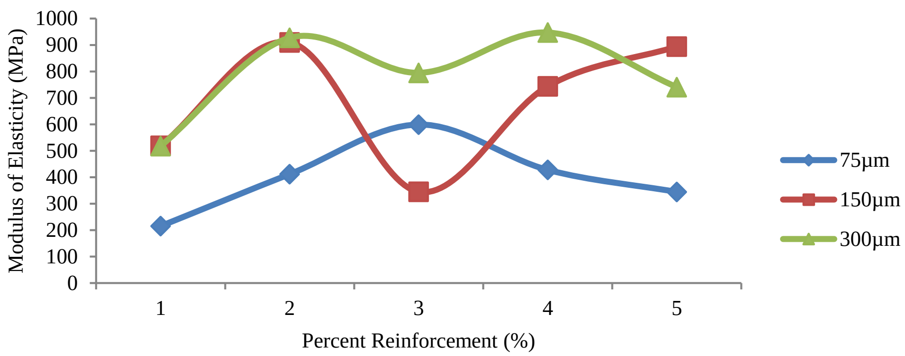

Fig. 5. Effect of reinforcement on Modulus of Elasticity of Coconut Husk Ash reinforced composite

The modulus of rupture of composite with 150µm ash particles increased from 22.90MPa at 5% reinforcement to a maximum value of 38.57MPa at 10% reinforcement and decreased to 37.69MPa at 25% reinforcement. The modulus of elasticity portrayed a similar result as it increased from 519.00MPa at 5% reinforcement to a maximum value of 909.95MPa at 10% reinforcement and decreased steadily to 894.00MPa at 25% reinforcement.

Modulus of rupture of composite made with 300µm ash particles increased from 517.84MPa at 5% reinforcement to 927.12MPa at 10% reinforcement. A decrease was observed at 15% reinforcement before it increased to a value of 947.12 at 20% reinforcement and then finally decreased to 740.19 at 25%.

Generally speaking, modulus of rupture and modulus of elasticity increased as the particle size increased, with 300µm particle size composite having the highest value of modulus of elasticity (947.12MPa). The highest value of modulus of rupture (38.57MPa) was obtained from 150µm, however, it can be seen that this value is only slightly higher than the one obtained from 300µm (37.00MPa). With respect to weight percentage of reinforcement, the moduli increased to a maximum, beyond which any further increase in reinforcement decreased the moduli; an exception to this trend was however observed on modulus of rupture of composites made from 75µm particles which increased continually.

Flexural properties of polymer composites depend mainly on the microstructure of a composite, and the interfacial bonding between the reinforcement and the matrix [17]. Therefore, the increase in flexural strength of the composites is due to the strong interfacial adhesion between the particles and the matrix which enhanced load transfer, while a later decrease in flexural properties is due to agglomerate formation at higher concentration of the reinforcement material in the composite [12].

Impact test

The result of impact test carried out on the composite is as shown in Table 1 and Figure 6. The impact energy of composite reinforced with 75µm particle increased from 0.13J at 5% reinforcement to a maximum of 0.37J at 25%. The result of composites reinforced with 150µm increased from 0.23J at 5% to a maximum value of 0.58J, while the composite with 300µm particles increased from 0.30J to a maximum value of 0.36J Generally, it was observed that the impact energy increased for composites of all the particle sizes with composite reinforced with 10% of 150µm particles of coconut ash having the highest value of 0.58J. The continous increase in impact strength of the composite made from different particle was due to increase in elasticity of the composites thereby increasing the deformability of the matrix material [12].

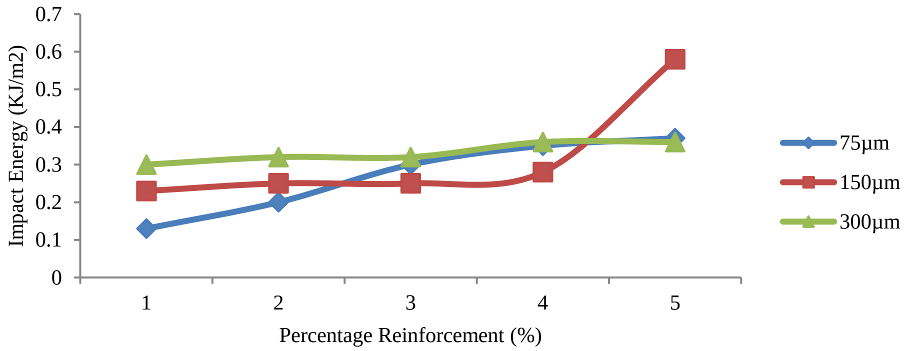

Fig. 6. Effect of reinforcement on impact strength of coconut husk ash reinforced composite

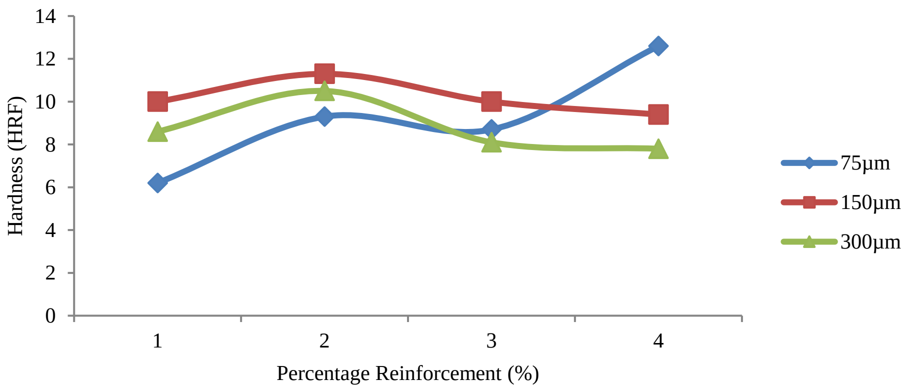

Fig. 7. Effect of reinforcement on hardness of coconut husk ash reinforced composite

Hassan *et al.*, [18] however reports an increase in impact energy of eggshell particle reinforced polyester composite to a maximum value of 0.35J at 30% of carbonized eggshell, after which there was a decrease. Shehu *et al.*, [19] also reports an initial increase in impact value of palm kernel shell particulate composite to a maximum of 0.4J and then a decrease. This trend could possibly be due to the inability of the reinforcement to block the crack propagation thereby reducing the impact strength [12].

Hardness test

The result of hardness test carried out on the composite is as shown in Table 1 and Figures 7. The hardness of the CHA composite was seen to increase with increase in reinforcement to a maximum value beyond which there was decrease, with the exception of composite of 75μm particles. Composite of 75μm particles increased from 4.3 to 12.6HRF; those of 150μm increased from 9.5 to 11.3HRF and then decreased to 9.4HRF while composites with 300μm particles increased from 7.1 to 10.5HRF and then decreased to 7.8HRF. Shehu *et al.*, [19] also reported an initial increase in hardness value of palm kernel shell particulate composite to a maximum, and then a decrease beyond that point. Olumuyiwa *et al.*, [20] reported a similar maximum hardness value for CCS composite (11.4HRF) which was obtained by steady increase as the reinforcement increased.

Conclusion

The research successfully developed a particulate polymer composite of polyester resin with varying particle sizes and contents of coconut husk ash. The results show that, generally, the influence of particle sizes of coconut husk ash on the mechanical properties of the composite was more pronounced than the particle content. The influence of particle sizes on tensile strength and Young's Modulus were significant; variation of particle contents began to follow an increasing trend but later became irregular. Modulus of Elasticity and Modulus of Rupture were significantly affected by particle size variation than particle content variation. There was no marked influence of particle size and content variation on the impact energy of the composite. The influence of particle size on hardness of composites was more significantly affected than the influence of particle content. This composite can be utilized in the automobile and sports equipment industries.

References

[1] G.B. Nyior, S.A. Aye, S.E. Tile, *Study of Mechanical Properties of Raffia Palm Fibre/Groundnut Shell Reinforced Epoxy Hybrid Composites*, **Journal of Minerals and Materials Characterization and Engineering**, **6,** 2018, pp. 179-192.

[2] N.J. Ogbodo, P.A. Ihom, O.N. Denis, *The Comparison of Micro Mechanics Analyses to Some Empirical Properties of Ukam (Cochlospemum Planconii)Fibre Reinforced Polyester Composite,* **Mechanics of Material Science and Engineering**, 2017, pp. 7-16

[3] O.O. Daramola, O.S. Akintayo, *Mechanical Properties of Epoxy Matrix Composites Reinforced with Green Silica Particles,* **ANNALS of Faculty Engineering Hunedoara– International Journal of Engineering**, **15,** 2017, pp. 167-174

[4] R.S.S. Raju, G.S. Rao, *Assessment of Tribological performance of Coconut Shell Ash Particle Reinforced Al-Si-Fe Composites using Grey-Fuzzy Approach,* **Tribology in Industry**, **39(3),** 2017, pp. 364-377.

[5] T.D. Ipilakyaa, C.N. Dagi, L.T. Tuleun, *Effects of Filler Content and Particle Size on the Mechanical Properties of Unsaturated Polyester Resin Reinforced with Rice Husk-Coconut Shell Particles*, **European Journal of Advances in Engineering and Technology**, **4(8),** 2017, pp. 637-643.

[6] R. Karthick, K. Adithya, C. Hariharaprasath, V. Abhishek, *Evaluation of mechanical behavior of banana fibre reinforced hybrid epoxy composites,* **Materials Today: Proceedings**, **5(5),** 2018, pp. 12814-12820.

[7] V.M. Manickavasagam, B.V. Ramnath, C. Elanchezhian, V.
Aravinthan, A.Vignesh, *Natural fibre composites-A Review*, **IOP Conf. Series: Materials Science and Engineering, 390,** 2018, pp. 1-6.

[8] J. Barton, A. Niemczyk, K. Czaja, L. Korach, B. Sachermajewska, *Polymer Composites, Biocomposites and Nanocomposites: Production, Composition, Properties and Application Fields.* **CHEMIK, 68(4),** 2014, pp. 280–287.

[9] T. Y. Ding, Production of Bioethanol by using Pretreated Coconut Husk as Carbon Source, A Master's Degree Thesis Submitted to Faculty of Engineering and Science, University of Tunku Abdul Rahman, 2014.

[10] T. Y. Ding, S. L. Hii, L. G. A. Ong, *Comparison of Pretreatment Strategies For Conversion of Coconut Husk Fibre to Fermentable Sugar*, **BioResources**, **7(2),** 2012, pp. 1540-1547.

[11] T. Saira, A. M. Munawar, K. Shafi Ullah, *Natural Fiber-Reinforced Polymer Composites*, **Proceedings of Pakistan Academy of Sciences**, **44(2),** 2007, pp. 129-144.

[12] A. Mishra, *Mechanical Properties of Cocconut Shell Dust, Epoxy - Fly Ash Hybrid Composites*, **American Journal of Engineering Research (AJER), 6(9),** 2017, pp. 166-174.

[13] ASTM D638, American Society for Testing and Materials (ASTM) Standard Test Method for Tensile Properties of Plastics.

[14] ASTM D790-03, American Society for Testing and Materials (ASTM) Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.

[15] ASTM D256, American Society for Testing and Materials (ASTM) Standard Test Method for Determining the Izod Pendulum Impact Resistance of Plastics

[16] J.O. Akindapo, E.T. Agov, D.K. Garba, R.O. Ogabi, *Comparative Assessment of Mechanical Properties of Groundnut Shell and Rice Husk Reinforced Epoxy Composites,* **American Journal of Mechanical Engineering**, 2017, 5(3), pp. 76-86.

[17] S. Hendra, M. Yovial, S. Edi, R.Roni, *Properties of graphite/epoxy composites: the in-plane conductivity, tensile strength and Shore hardness*, **AIMS Materials Science, 6(2),** 2019, 165-173.

[18] R. Rahmi, M. Marlina, N. Nisfayati. *Effect of Eggshell on Mechanical Properties of Epichlorohydrin Cross-linked Chitosan/Eggshell Composites*, **Oriental Journal of Chemistry**, **33(1),** 2017, pp. 478-482.

[19] U. Shehu, O. Aponbiede, T. Ause, E.F. *Obiodunukwe, Effect of particle size on the properties of Polyester/Palm Kernel Shell (PKS) Particulate Composites,* **Journal of Material Environmental Science**, **5(2),** 2014, pp. 366-373.

[20] J. A. Olumuyiwa, S. I. Talabi, O. S. Sanni, *Study of Mechanical Behaviour of Coconut Shell Reinforced Polymer Matrix Composite.* **Journal of Minerals and Materials Characterization and Engineering**, **11,** 2012, pp. 774-779.

Received: June 11, 2019
Accepted: August 18, 2019