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CHARACTERIZATION AND EVALUATION OF MAHOGANY (*KHAYA IVORENSIS*) DUST-EGG SHELL-EPOXY COMPOSITES

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Abstract: The conversion of bio-agricultural wastes into composite material for engineering applications is a strategy to add more value in waste utilization and help in the composites with epoxy resin and 10 wt.% NaOH treated *Khaya ivorensis* dust and egg shell particles were prepared by open molding technique. Tensile strength, flexural strength and hardness tests were carried out to evaluate the composite mechanical properties. The results showed that the tensile and flexural strengths increase with addition of reinforcement materials. The composite sample with 3 wt.% wood dust and 10 wt.% egg shell particles displayed highest tensile strength of 34.87 MPa, while the composite sample with 10 wt.% wood dust and 10 wt.% egg shell particles have highest flexural strength. Hardness value of the composite increases with addition of reinforcement materials and maximum at 5 wt.% wood dust and 10 wt.% egg shell particles. In addition, water absorption characteristics of the composite increases with increasing percentage of wood dust. Optimum composition of wood dust and egg shell can be used to produce polymer matrix composites with good mechanical properties.

Keywords: Eggshell, *Khaya ivorensis* dust, mechanical properties, composites

INTRODUCTION

In recent time, interest in composite material has been on the increase due to its unique properties compare to other engineering materials. Composite material refers to a multiphase material composed of distinct constituent, known as reinforcement, distributed in a continuous phase known as the matrix, and resulting in a material with properties that are significantly different and not achievable using each constituent on their own. Combination of two or more materials with different properties without blending or dissolving them into each other formed composite materials [1].

Composite materials are significantly used in different major applications, such as in transportation, medical applications, oil and gas, aerospace, construction and infrastructure, energy, marine, recreation and sports, among others. This is due to the advantages they have over other materials in terms of properties like light weight, resistant to corrosion, design flexibility and processing, durability, strength, magnetic properties, and good conductors or insulators of heat [2].

Development of composites using bio-agricultural by-products (like egg shell, wood, etc) makes it possible to achieve materials of good mechanical properties, such as material with equal strengths, both in tension and compression [1,2,3,4]. Development of composites helped to overcome deficiencies in some materials [3]. The use of bio-agricultural wastes (like wood dust and egg shell) in the development of composites helps to achieve materials of low cost, less health risk, comparable specific tensile properties; and with non-irritation to skin, bio-degradability, renewability, and non-abrasive to the equipment [5].

Wood is a natural composite material which finds applications in building constructions, automobile, furniture works etc. Wood dust (saw dust) is a by-product of wood processing which are largely discarded as wastes into the environment. In Nigeria, about 1.8 million tons of wood dust is generated annually [6]. The use of wood dust as a filler in composite material has been increasing over the years for various applications such as in housing, automotive, aerospace etc. [7]. Recycling of wood dust for use as a constituent of composite material would help in reducing environmental pollution and also increase the spectrum of value addition to wood processing by-products.

Chicken eggshell is an important agricultural by-product that causes environmental pollution, most especially in countries where developed egg product industries are located. Annually, eggshells are disposed of in landfills as a waste mostly all over the world [8]. Several attempts have been made to use the chicken eggshell for various applications. Good availability and chemical composition of chicken egg shell make it a worthwhile constituent material in the production of polymer matrix composites [[9].

Environmental problems that are caused by irresponsible disposal of wastes are drastically reduced if agricultural wastes are adequately utilized [10]. Environmental and health quality will be protected by searching for effective and proper way of managing agricultural wastes [10]. Usage of bio-agricultural wastes will help to obtain value added products (such as biomaterial used in medical surgery and therapeutics, and in production of automobile components), a side from environmental protection. To achieve sustainable development, waste utilization is a priority [11].

In this study, characterization of the polymer matrix composite formed from combination of wood dust and egg shell particles reinforced were investigated to ascertain their suitability for engineering applications. This will also help to promote development of polymer matrix composite, a biodegradable material which is highly desirable in many applications of human endeavors.

MATERIALS AND METHODS

— Materials and equipment

Khaya ivorensis dust was sourced locally from a saw mill in Tanke area of Ilorin, Kwara state. The chicken egg shells were sourced from the waste bins of restaurants also in

Tanke area of Ilorin, Kwara State. The collected egg shells were thoroughly washed with fresh water to remove impurities, including the thin membrane. *Khaya ivorensis* dust and egg shell were oven-dried at 80°C for 24 hours to remove the moisture. Dried egg shells were pulverized to obtain egg shell particles using ball milling machine and sieved to 0.5 mm particle size. The elemental compositions of the eggshell were determined through SEM/EDS analysis.

Khaya ivorensis dust was sieved to 1.0 mm particle size. Epoxy resin and hardener were purchased at a chemical store in Lagos. The matrix was prepared by mixing epoxy resin with 2wt.% hardener in line with the practice of Anjali *et al*. [12]. Equipment used are: digital weighing balance, oven, spatula, universal (testometric) testing machine, sieves, mixing bowls, gloves, masking tape, scissors, sodium hydroxide solution (NaOH) and distilled water. Wooden moulds were fabricated at Temitope Furnitures in Tanke area of Ilorin, Kwara State, Nigeria.

— Surface treatment of wood dust and egg shell particles

Surface treatment of wood dust and egg shell particles was carried out by soaking them separately in 10wt.% solution of NaOH for 24 hours at room temperature and stirred thoroughly, after which they were separated with sieve, washed with distilled water and oven dried at 110°C until constant weight was achieved. The treatment with sodium hydroxide is necessary in order to improve interfacial bonding between the matrix and reinforcements and hence, better mechanical properties of the composite [13,14, 15].

— Composites fabrication

Various mixing proportion of wood dust, egg shell particles and epoxy resin, as presented in Table 1, were properly mixed together for a period of 5 minutes to obtain homogeneous mixture of the constituents before pouring into the mould. After pouring, the composites were left in the mould for 24 hours to solidified, then, removed and placed in an oven for 6 hours at 40°C to properly harden and cure.

Table 1: Mixing ratio of wood dust, egg shell particles and epoxy resin

Samples Designation	% of Wood dust (g)	% of Egg shell particles (g)	% of Epoxy resin (g)
A	-	-	100
B	10	-	90
C	10	3	87
D	10	5	85
E	10	10	80
F	3	10	87
G	5	10	85

MECHANICAL TESTS

— Tensile test

The composite samples' tensile strengths were determined according to ASTM D638 standards [16] using Computerized Testometric Testing Machine (Model No 0500-10080, Win test analysis; 100 KN capacity, England made). Each test sample was tightly held between the two grips of the testing machine and a progressively increasing load was applied on the test sample at a constant rate of 2 mm/minute. As the load increased, deformation readings were automatically recorded until rupture of the sample occurred. Three samples of each composite composition were used for the test and the average values were recorded.

— Flexural test

The composites flexural strengths were determined in accordance with the guidelines in ASTM D790 standards [17] using Computerized Testometric Testing Machine. Three point bend flexural test method was used. The machine applied a progressively increasing load on the composite at a constant rate of 2 mm/minute until it fractured. Three samples of each composite composition were used for the test and the average values were recorded.

— Hardness test

The hardness property of the samples produced was determined using Brinell hardness tester with indenter ball diameter of 20 mm and maximum load of 4000 N. The impression or indentations created on the composites were measured across at least two diameters at right angles to each other and the average values were obtained. The Brinell Hardness Number (BHN) was calculated using equation 1 [18].

WATER ABSORPTION TEST

Each of the sample's water absorption rate was determined by soaking the composite samples in water for 24 hours. The initial weight of each sample was taken and recorded as W_o before soaking in water. After 24 hours, samples were brought out, cleaned to remove water on the surfaces, re-weighed and recorded as W_1. Differences in initial and final weights of each sample were then used to determine water absorption rate. This was calculated using equation 1.

$$\text{Water absorption rate (\%)} = \frac{w_1 - w_0}{w_0} \times 100 \qquad (1)$$

RESULTS AND DISCUSSION

— Elemental compositions of the eggshell

The results of the EDS analysis revealed the elemental compositions of the eggshell presented in Table 2. The components of the eggshell as shown in Table 2 are in descending order of Ca, O, k, Al, Na, Mg and lastly Si. This implies that the major components are Ca, O and k. This result is similar to results obtained by Jenniffer *et al.* in their studies [19].

Table 2: Elemental compositions of the egg shell particles

Elements	Ca	Mg	Na	Al	O	K	Si
Percentage Weight Composition (%)	80.1	0.21	0.35	0.36	11.6	7.3	0.08

— Tensile test

Figure 1 showed that composite sample F (3 wt. % wood dust, 10 wt. % egg shell particles and 87 wt. % epoxy resin) has the highest tensile strength of 34.87 MPa, while composite sample B (10 wt. % wood dust and 90 wt. % epoxy resin) has the lowest tensile strength of 30.05 MPa. The superior tensile strength of the composites compared to the control sample A (100% epoxy resin) may be attributed to the presence of the wood dusts and egg shell particles in the matrix as natural fibres which possibly lock up dislocations and improves the strength and stiffness of the composites [20] and yet maintain some ductility. Ductility is a measure of how much strain a material can withstand before rupturing, that is, its ability to stretch before failure [21,22]. Under loading, Composite sample C (10 wt. % wood dust, 3 wt. % egg shell particles and 87 wt. % epoxy resin) showed appreciable amount of ductility.

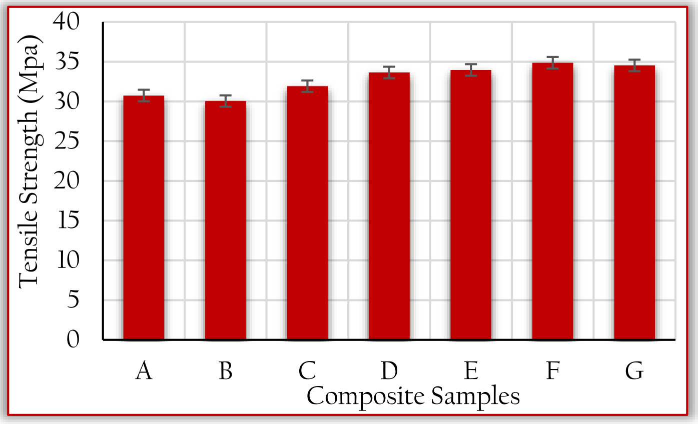

Figure 1: Tensile strength of the composites

— **Flexural test**

Figure 2 showed the effect of wood dust and egg shell particles addition on the flexural strength of the composites. Sample E (10 wt. % wood dust, 10 wt. % egg shell particles and 80 wt. % epoxy resin) has the highest flexural strength of 45.70 MPa, while sample C (10 wt. % wood dust, 3 wt. % egg shell particles and 87 wt. % epoxy resin) has the lowest flexural strength of 36.85 MPa. The flexural strength of control sample A (100% epoxy resin) is 29.59 MPa. It was also observed from the results that the flexural strength was enhanced at higher content of egg shell particles. Lower particle size of the egg shell compared to that of the wood dust may be responsible for the enhanced flexural strength.

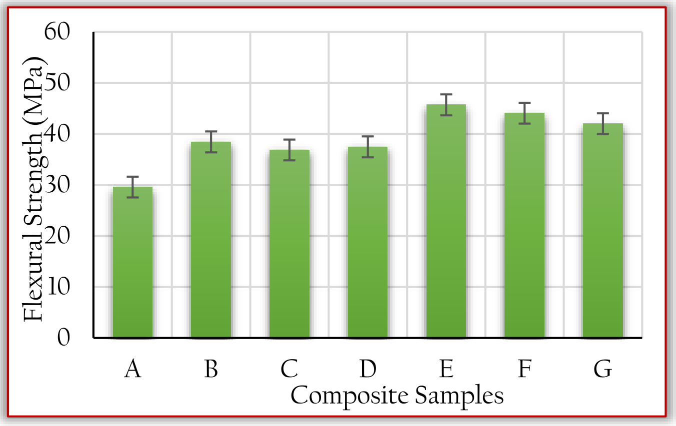

Figure 2: Flexural strength of the composites

— **Hardness test**

Generally, significant improvement in hardness was observed in all composition of the samples as presented in Figure 3. Composite sample G (5 wt. % wood dust, 10 wt. % egg shell particles and 85 wt. % epoxy resin) possessed highest hardness value compared to all other investigated samples. Highest hardness value obtained here may be due to higher quantity of egg shell particles compared to the quantity of wood dust in the composition of the sample. This result is consistent with the observation of Hassan *et al.* [9]. Improvement in hardness of these composites is an indication that they would have good wear resistance, compared to unreinforced sample.

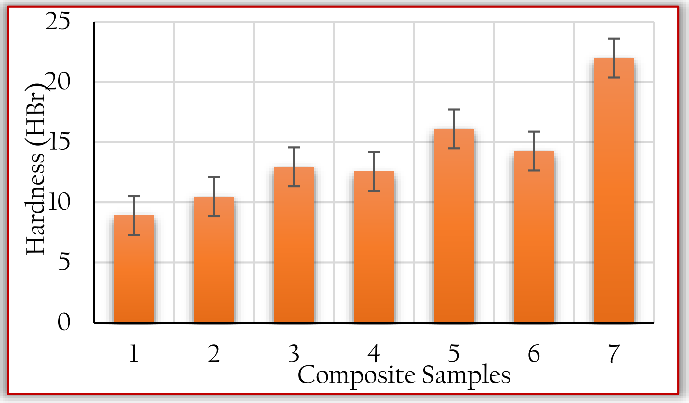

Figure 3: Hardness of the composites
where: 1 = A, 2 = B, 3 = C, 4 = D, 5 = E, 6 = F, and 7 = G on the graph

— **Water absorption test**

Figure 4 showed water absorption test results obtained after 24 hours of soaking the composites. The control sample A (100% epoxy resin) has the least water absorption rate of 2.62 %, while composite sample D (10 wt. % wood dust, 5 wt. % egg shell particles and 85 wt. % epoxy resin) has the highest water absorption rate of 5.91%. From the results, it was noted that the composites with higher quantity of wood dust absorbed more water as a result of hydrophilic nature of wood dust. This is consistent with the finding of Narayan and Antaryami [23]. Conversely, composites with higher quantity of egg shell particles absorbed less water. This may be attributed to lower porosity of egg shell particles compared to the wood dust.

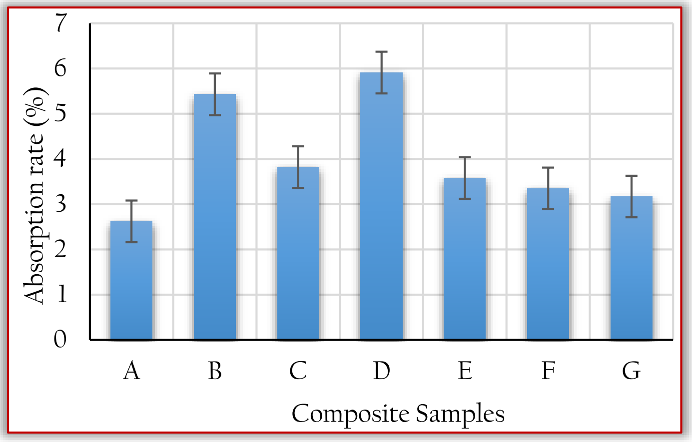

Figure 4: Water absorption rate of the composites

CONCLUSIONS

The following conclusions have been drawn from the results of this study:

— The tensile strengths of the composite increases with addition of reinforcement materials and maximum at 3wt.% wood dust and 10wt.% egg shell particles.
— The flexural strengths of the composite increases with addition of reinforcement materials and maximum at 10wt.% wood dust and 10wt.% egg shell particles.
— The hardness value of the composite increases with addition of reinforcement materials and maximum at 5wt.% wood dust and 10wt.% egg shell particles.

— The water absorption rate of the composite increases with increasing percentage of wood dust. This may be attributed to the hydrophilic nature of wood dust.
— Mahogany wood dust and egg shell particles which are regarded as wastes were found suitable in the production of reinforced epoxy composites by open moulding technique.

References

[1] Jim W. (2021) Sience and Tehnology of Composite Materials - Curious. Austrian Academy of Science. Retrieved from https://www.science.org.au/curious/techology-future/composite-materials, on 29/6/2021.
[2] Tri-Dung N. (2021). Introdction to Composite Materials. Retrieved from https://www.intechopen.com/books/composite-and-nanocomposite-materials-from-knowledge-to-industrial-applications/introduction-to-composite-materials, on 29/6/2021
[3] John, V (1992). Introduction to Engineering Materials: Macmillan Press Ltd., London, 1-503
[4] Ambali, I. O. , Shuaib-Babata Y. L. , Alasi T. O., Aremu I. N., Ibrahim H. K., Elakhame Z. U., Abdulraman S. O. (2019). Suitability of Cow Horn as Filler in an Epoxy Composite,, Journal of Applied Science, Environmental and Management, 23 (3), 475-482
[5] Malkapuram, R; Kumar, V; Negi, YS (2009). Recent Development in Natural Fiber Reinforced Polypropylene Composites. J. Reinforced Plastics Composites, 28(10), 1169-1189
[6] Owoyemi, J. M., Zakariya, H. O., And Elegbede, I. O. (2016). Sustainanble Wood Waste Management In Nigeria. *De Gruyter*, 4(3), 1 - 9.
[7] Moh'd-Idris, M. A., Hamdan, S., Rahman, M. R., and Islam, M. S. (2011). Treated tropical wood sawdust-polypropylene polymer composite: mechanical and morphological study. *Journal of Biomaterials and Nanobiotechnology*, 2, 435-444.
[8] Nadir B., Chen Y., Xiang P., Gulzar H. J., Shao Y. (2018). Chicken Eggshell as a Potential Eco-friendly, Low-cost Sorbent: A Mini Review, Journal of Environment and Earth Science, 8(10), 29-39.
[9] Hassan, S. B., Aigbodion, V. S. And Patrick, S. N. (2012). Development Of Polyester/Eggshell Particulate Composites. *Tribology In Industry*, 34(4), 217-225.
[10] Idris A., Hamzat I. T., Bashir A. M., Haruna S., Hindatu Y., Mohammed N. J. and Sulaiman M. (2014). From Garbage to Biomaterials: An Overview on Egg Shell Based Hydroxyapatite, Journals of Materials, 2014, 1-6.
[11] [11]Seidi T. A. and Holm-Nielsen J. B. (2004). Agricultural Wastes, in Waste Management Series, Twardowska I, and William, J. L. Eds., Elsevier.
[12] Anjali R. M., Shivani Bhandari A. P., ArpitSaxena S., Nitin Kumar N. C., Dheeraj G., Sah P. L., (2017). Fabrication of Mechanical Testing of Egg Shell Particles Reinforced Al-Si Composites. International Journal of Mechanical Engineering and Management Sciences, @(1), 53-62.
[13] Paschal A. U. and Salawu A. A. (2015). Effect of Sodium Hydroxide Treatment on the Mechanical Properties of Crushed and Uncrushed, World Academy of Science, Engineering and Technology International Journal of Chemical, Nuclear, Materials and Metallurgical Engineering, 9 (1), 203-208.
[14] Sepe R., Bollino F., Boccarusso L., Caputo F. (2017). Influence of Chemical Treatments on Mechanical Properties of Hemp Fiber Reinforced Composites, S1359-8368(17)32791-9
[15] Shehu U, Isa M. T., Aderemi B. O. and Bell T. K. (2017). Effects of NaOH Modification on the Mechanical Properties of Baobab Pod Fiber Reinforced LDPE Composites, Nigerian Journal of Technology, 36(1), 87 – 95
[16] ASTM D38-14, Standard Test Method for Tensile Properties of Plastics, ASTM International, West Conshohocken, PA, 2014, www.astm.org
[17] ASTM D790 – 17, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials,
[18] Ghosh, A. K. (2005). A textbook on an introduction to engineering materials and manufacturing processes (3rd edition). Prentice-Hall of India Private Limited, New Delhi, India
[19] Jenniffer S. O. S., André G. S. G. (2018). Bioceramic Composite: Hen's Eggshell Characterization and Main Applications, Revista Ifes Ciência, – Instituto Federal do Espírito Santo, 4(1), 1-12.
[20] Manikandan, N., Sabu, T., And Gabriel, G. (2001). Thermal And Dynamic Mechanical Analysis Of Polystyrene Composites Reinforced With Short Sisal Fibres. *Composites Science And Technology*, 61(16), 2519 - 2529.
[21] Ductility-an Overview, Elsevier. Retrieved from https://www.sciencedirect.com/topics/chemistry/ductility on 29/6/2021.
[22] Steven E. H. (2009). Materials and Their Weldability, In A Quick Guide to Welding and Weld Inspection. Elsevier.
[23] Narayan, C. N., and Antaryami, M. (2013). Development and mechanical characterization of palmyra fruit fiber reinforced epoxy composites. *Journal of Production Engineering*, 16(2), 69 - 72.

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