Journal of Materials Science Research and Reviews

1(3): 98-107, 2018; Article no.JMSRR.43847

Characteristics and Reliability of Polyurethane Wood Ash Composites for Packaging and Containerisation Applications

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Authors' contributions

This work was carried out in collaboration between all authors. Authors CEO and EJO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors CEO and CCI managed the analyses of the study. Author JJO managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JMSRR/2018/43847
Editor(s):
(1) Dr. Yong X. Gan, Professor, Department of Mechanical Engineering, California State Polytechnic University, Pomona, USA.
Reviewers:
(1) Ahmad Adlie Shamsuri, Universiti Putra Malaysia, Malaysia.
(2) Blessed Dimas Jen, Taraba State University, Nigeria.
(3) Phyu Phyu Myint, Sittway University, Myanmar.
(4) Josephine Lai Chang Hui, Universiti Malaysia Sarawak, Malaysia.
Complete Peer review History: http://www.sciencedomain.org/review-history/26269

Original Research Article

Received 15 June 2018
Accepted 13 September 2018
Published 16 September 2018

ABSTRACT

Aims: The aim of the study is to evaluate polyurethane wood ash composites characteristics and reliability.
Study Design: Experimental Study Design was used in the study.
Place and Duration of Study: The study was conducted in the faculty of Engineering workshop, Nnamdi Azikiwe University, Awka, Nigeria from October 2017 and February 2018.
Methodology: Three independent parameters employed include carbonisation temperature, particle size and volume fraction. *Gmelina arborea* samples were sundried and carbonised at varied temperature (400,700 & 1000°C), sieved to three particle sizes (75, 150 & 300 μm) and

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reinforced at varied volume fractions (30, 40 & 50%) with Polyurethane elastomeric polymer. The mechanical properties of the various samples prepared were tested and Weibull statistics was adopted in strength analysis of the composite.

Results: The results obtained showed that varying carbonisation temperature resulted in different mechanical properties of the wood ash composites with the best improvement occurring at 50% volume fraction, having 300 μm particle size at carbonisation temperature of 700°C. However, decrease in the density of the composite was noticed when the fiber volume fraction increased. In all cases, carbonisation above 400°C showed improved mechanical properties as a result of increased carbon yield and reduction in tar and moisture content.

Conclusion: A low Weibull modulus of 1.64 suggests that polyurethane wood ash composites has highly variable fracture strength, making it difficult to be used reliably in load-bearing applications, however more useful applications of the new material may include packaging and containerisation.

Keywords: Reliability; polyurethane; wood ash; composites; Weibull distribution.

1. INTRODUCTION

There is a change in outlook occasioned by the development of ecological mindfulness and search for packaging and containerisation materials which are biodegradable and environment friendly. It might be said that biodegradability is not just a utilitarian prerequisite but also a critical natural trait. Along these lines, the idea of biodegradability appreciates both easy to use and eco-friendly materials which are basically gotten from replenishable timber waste and accordingly it profits by common asset preservation with a supporting on naturally amicable and safe atmosphere [1,2].

Gmelina arborea (melina) was originally introduced in large tropical areas due to their fast growth characteristics ease of management in short rotation systems [3,4]. Classical uses, microscopic, botanical descriptions, chemical constituents and pharmacological characteristics of *Gmelina arborea* wood has been reported elsewhere [5,6]. Significant research efforts is missing on the utilisation of this cellulosic material in composite formulation, hence the present study provides beneficial directions to explore further application of *Gmelina arborea* wood in polymer engineering applications.

Studies involving the use of agricultural waste in polymer composite development abound in literature. Iloabachie, Obiorah, Ezema, Henry, Chime [7] examined the effect of carbonisation on the physic-mechanical properties of coconut shell/unsaturated polyester composite. Subyakto and Gustan [8] observed the effect of temperature and time of carbonisation on the properties of bamboo carbon considering the chemical components of raw bamboo particles. Ihueze, Obiafudo & Okafor [9] studied biofibers in polymer matrixes. Shakuntala, Samir, Raghavendra [10] studied the characterisation and wear behavior of carbon black filled polymer composites. Malte and Holger [11] examined the reinforcement of polymer matrix composite using carbon residues derived from woody biomass. Akanbi, Onuoha, Elele, Nwogu [12] evaluated the effect of carbonised saw dust on the tensile and flexural strength of polyolefin plastics.

Mechanical and physical properties of polyurethane reinforced with different natural and biodegradable contents has been reported in literature, every reinforcement type and combination has its own advantages and disadvantages, multiple studies demonstrated varying properties of polyurethane reinforced with polycaprolactone [13], jute fiber [14], glass fiber [14,15], hemp fiber [16], kenaf fiber [17], rice husk [18], sugarcane bagasse and sisal [19], carbon black N990 particles [20], modified castor oil polyols [21], bambara nut shell and corn chaff [22], coconut coir fiber [23], *Alstonia boonei* wood fiber [24], groundnut husk powder [25]. The studies showed extensive use of natural fibers in reinforcing polyurethane matrix. Nonetheless, studies relating to *Gmelina arborea* (melina) as filer in polyurethane polymer are scarce in literature.

Food bundling and packaging advancements have continually developed over the years to beat challenges in the globalised purchaser showcase. Most of the materials (glass, metal, paper, composites and plastics) for sustenance packaging and containerisation, plastic possessed over 40% of the bundling market because of their various favorable flexibility and minimal cost [26,27]. Composites with different types of reinforcement has been developed by researchers for different application, Ihueze, Obiafudo and Okafor [9] characterised plantain fiber reinforced high density polyethylene composite for application in design of auto body fenders; obviously, new research is needed to further delineate the specificity between reliability and material performance, this is because typical cellulosic composite exhibit pronounced ductility and often failed in pure flexural mode.

The strength of composites depends upon the size and distribution of sizes of flaws originated during processing and manufacturing [28]. Therefore strength of composite material depends upon the probability of finding a flaw that exceeds a certain critical size. The Weibull distribution is an indicator of the variability of strength of materials resulting from a distribution of flaw sizes. The Weibull statistic has been widely used in the recent years to describe the statistical behaviour of the strength properties of polymeric matrix composites [29,30]. The c also describes the fracture toughness of engineering materials where failure occurs by cleavage [31,32,30]. Very essential aspect of Weibull distributions is the Shape Parameter (m) which has a particular impact is the hazard rate. As is shown in Fig. 1, Weibull distributions with $m < 1$ have a hazard rate that decrease with time which is called early-life failure. When m gets closer to 1, there will be fairly constant failure rate indicating useful life/random failures. However, when $m > 1$, there will be failure rate that increases with time indicating the stage of wear-out failures. These stages makes up the three sections of three sections of the classic bathtub curve. A mixed Weibull distribution with one subpopulation with $m < 1$, one subpopulation with $m = 1$ and one subpopulation with $m > 1$ would have a failure rate plot that was identical to the bathtub curve [30]. Ihueze, Achike and Okafor [33] verified the performance characteristics of coconut fibre particles reinforced high density polyethylene, Okafor and Godwin [34] evaluated of compressive and energy adsorption characteristics of natural fiber reinforced composites, they conclude that fabrication of fiber reinforced composites consisting of plantain fiber reinforcement in polyester matrix is possible.

Ihueze and Okafor [35] optimally designed for flexural strength of plantain fibers reinforced polyester matrix in which the optimum values of the control factors were established. Literature has shown that the properties of polymer composites can be influenced by many factors, furthermore, tensile [36], flexural [37] and compressive [38] responses of wood ash particles reinforced polypropylene composite has been studied in literature, however these materials were evaluated in terms of failure strength only; the researches were rigorously carried out for characterisation of wood based composites without recourse to their reliability during application. Expanding our understanding on the strength and reliability would add to the development of a more highly specified model of engineered composites. From the foregoing, the need to explore *Gmelina arborea* (melina) cellulosic waste for functional reinforcement in polymer matrix has become very imperative; the objective of this study therefore is to evaluate the characteristics and reliability of polyurethane wood ash composites.

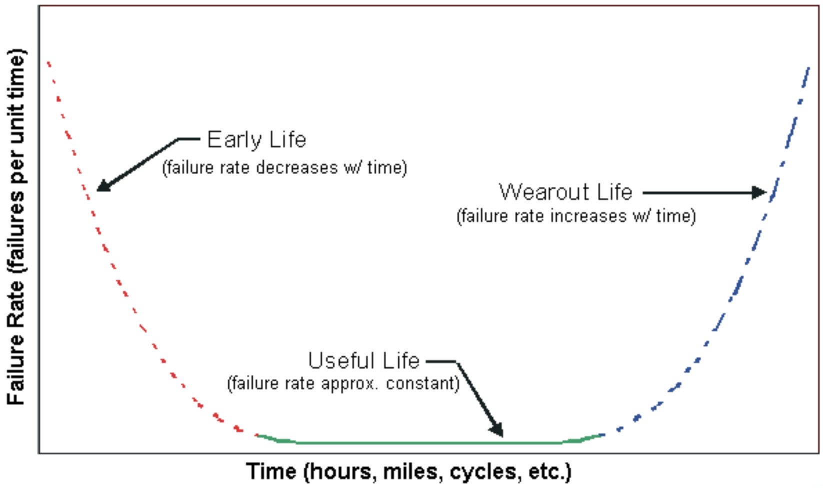

Fig. 1. The classic bathtub curve
Source: https://www.weibull.com/hotwire/issue14/relbasics14.htm

2. MATERIALS AND METHODS

2.1 Particle Size Analysis

The particle size analysis was carried out in the Civil Engineering laboratory at Nnamdi Azikiwe University, Awka. The ground carbonised sawdust weighing 200 g was poured into the particle size analyser 'impact laboratory test sieve' and was fixed on the mechanical shaking machine. The sieves were set in descending order, ranging from coarse to the finest mesh size and shaken for ten (10) minutes to have homogenous reinforcement-matrix interfacial mixture. Three filler sizes (75 μm, 150 μm, and 300 μm) were obtained each, for the three samples (400°C, 700°C and 1000°C) in accordance with ASTM standard.

2.2 Determination of Fiber Volume Fraction and Composite Sample Preparation

The volume fraction of wood ash samples was achieved following the derivations from the rule of mixtures based on the procedures of Jones [39] and implementation of Archimedes procedures. A mold of 200 mm × 200 mm × 5 mm having a base of glass and sides of wood was used for casting the composite sheets. A measuring cylinder was used to measure out the polyurethane resin and the corresponding wood ash filler samples were mixed and stirred with a mechanical stirrer for 60s before pouring in the mold. The volume fraction of the wood ash filler in the composite ranges from (30, 40 and 50%). Care was taken to avoid formation of air bubbles during pouring and the mixture, which was covered to avoid buckling and allowed to cure at room temperature for 48 hours. For quick and easy removal of the molded composite sheet, a mold release sheet was kept over the glass plate and wood sides. After curing, the laminate produced was trimmed and cut into required test specimen sizes for necessary tests.

2.3 Density Measurement Procedure

The material density was determined following ASTM D792 for density and specific gravity. Specimens of size 20 x10x 5 mm^3 was taken from the cast composite sheet and used for this purpose.

2.4 Tensile Test Procedure

Tensile test was carried out in accordance to ASTM D3039 for polymer matrix composite materials using rectangular sheets of 250 mm x 25 mm x 5 mm. Tests were done at ambient temperatures at a cross head speed of 5 mm/min giving rise to tensile strength, stress-strain, elongation at break and modulus

2.5 Flexural Test Procedure

Flexural test was performed using a three point loading system for center loading in accordance with ASTM D790 Standard Test Methods for Flexural Properties of Reinforced Plastics, 2015. The specimen lies on a support span and the load is applied to the center by the loading nose producing three-point bending at a cross head speed of 5mm/min. The specimen thickness is 4 mm and the width is 13 mm.

2.6 Weibull Statistics for Polyurethane Wood Ash Composites Strength Analysis

The Polyurethane wood ash Composites is considered as a body of volume *V* with a distribution of flaws and subjected to a stress σ. If we assumed that the volume, *V,* was made up of *n* elements with volume V_o and each element has the same flaw-size distribution, Askeland, Fulay & Wright [28] showed that the survival probability, $P(V_o)$, is given by

$$P(V_o) = \exp\left[-\left(\frac{\sigma-\sigma_{min}}{\sigma_0}\right)^m\right] \tag{1}$$

The probability of failure, $F(V_o)$, can be written as

$$F(V_o) = 1 - P(V_o) = 1 - \exp\left[-\left(\frac{\sigma-\sigma_{min}}{\sigma_0}\right)^m\right] \tag{2}$$

In equations 1 and 2, σ is the applied stress, σ_0 is a scaling parameter dependent on specimen size and shape, σ_{min} is the stress level below which the probability of failure is zero (i.e., the probability of survival is 1.0). In these equations, *m* is the Weibull modulus/shape parameter which is a measure of the variability of the strength of the material. However, there is no nonzero stress level for which we can claim a reinforced material will not fail [30,28]. Hence Equations 1 and 2 can be rewritten as follows:

$$P(V_o) = \exp\left[-\left(\frac{\sigma}{\sigma_0}\right)^m\right] \tag{3}$$

and

$$F(V_o) = 1 - P(V_o) = 1 - \exp\left[-\left(\frac{\sigma}{\sigma_0}\right)^m\right] \tag{4}$$

Assuming that all samples tested has same volume, thus the size of the sample will not be a factor in the present study, such that we can use the symbol V for sample volume instead of V_o. Hence equation 4 now becomes

$$F(V) = 1 - P(V) = 1 - \exp\left[-\left(\frac{\sigma}{\sigma_0}\right)^m\right] \quad (5)$$

or

$$1 - F(V) = \exp\left[-\left(\frac{\sigma}{\sigma_0}\right)^m\right] \quad (6)$$

Taking the logarithm of both sides

$$ln[1 - F(V)] = -\left(\frac{\sigma}{\sigma_0}\right)^m \quad (7)$$

Taking the logarithm of both sides again

$$\ln\{ln[1 - F(V)]\} = \mathrm{m}(\ln\sigma - ln\sigma_0) \quad (8)$$

We can eliminate the minus sign on the left-hand side of equation 8 by rewriting it as

$$\ln\left\{ln\left[\frac{1}{1-F(V)}\right]\right\} = \mathrm{m}(\ln\sigma - ln\sigma_0) \quad (9)$$

σ_0 represents the characteristic flexural strength of the composites. In equation 3, when $\sigma = \sigma_0$, the probability of survival becomes $\frac{1}{e} \cong 0.37\ or\ 37\%$. Therefore, σ_0 is the stress level for which the failure probability is ≅ 0.63 0r 63%. As the required probability of failure (*F*) goes down, the stress level to which the composite can be subjected (σ) also goes down [28].

3. RESULTS AND DISCUSSION

3.1 Initial Characterisation of Polyurethane Wood Ash Composites

The sample composition in the order of Particle size (µm)/Carbonisation temperature (°C)/Fiber volume fraction (%) following Taguchi L9 orthogonal array is presented in the Fig. 2.

Fig. 2 showed clearly that polyurethane composite has a significant flexural characteristics, the density of the composite as can be seen from the Fig. 2 recorded concomitant decreases as the fiber volume fraction increases. This gives credence to the observation made by previous researchers. According to Iloabachie et al. [7], the decrease in density with increase in volume fraction of the reinforced composite may be attributed to the light weight of fiber particles. However the density of the fiber carbonised @ 400°c recorded the highest density values, apparently in the entire volume fraction loading. This could be argued as a result of increased tar and moisture content in them.

The best improvement in the tensile strength of the wood composite samples is achieved when filled with 50% fiber volume fraction, having 300 µm particle size and carbonisation temperature of 700ºC. Generally, as could be seen in Fig. 2, the tensile strength of the composite samples increases with the increase in fiber volume

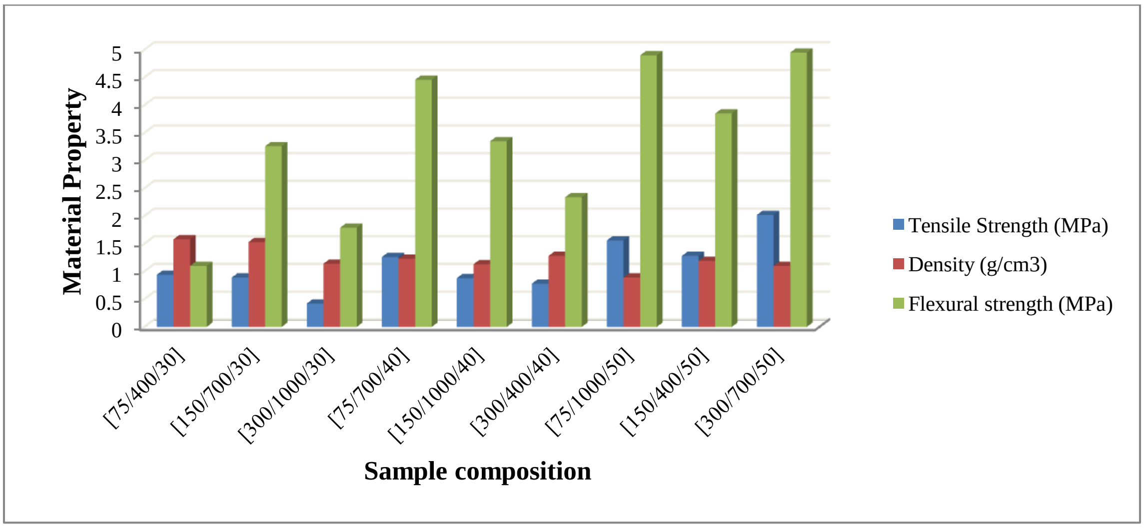

Fig. 2. Result of initial sample characterisation

fraction. A similar trend was reported by Salih, [40] and this is as a result of increase in the viscosity of the polyurethane matrix with the increasing fiber content and an indication to matrix/fiber interfacial bonding caused by decrease in the resin flow.

From the Fig. 2, it could be observed that in all cases of the wood composite samples, due to the strong nature of the polyurethane matrix, the flexural strength indicated improvements. However, the wood composite samples having 50% fiber volume fraction recorded concomitant increase in flexural strength more than any other samples. It could also be observed, that the wood composite samples is in agreement with the same trend reported by different authors [37,7] where the flexural strength of fiber reinforced composite increases with the increase in fiber volume fraction.

3.2 Modeling Flexural Responses of Polyurethane Wood Ash Composites

The experimental data was fitted using MATLAB plot function, a quadratic polynomial of equation 10 was found suitable in describing the flexural behavior of the composite as shown by the coefficient of determination (R^2 = 0.985). In Fig. 3 flexural strength of polyurethane wood ash composite increased with increase in volume fraction and attained maximum at 4.95 MPa between 45% to 50% volume fraction. More addition of reinforcement increased brittleness of the composite resulting from debonding micro processes leading to decline in flexural property [41].

$$F_s = -0.011V_f^2 + 1.084V_f - 21.51 \tag{10}$$

From equation 10,

$$F_s = -21.51 + 1.084V_f - 0.011V_f^2 \tag{11}$$

$$F_s = -21.51\left[1 - \frac{1.084}{21.51}V_f + \frac{0.011}{21.51}V_f^2\right] \tag{12}$$

$$F_s = -21.51[1 - 0.0504V_f + 0.0005V_f^2] \tag{13}$$

Taking F_{so} as the ultimate flexural strength at zero volume fraction, equation 13 can be compared to Guth's filler reinforcement model [42] such that equation 13 becomes.

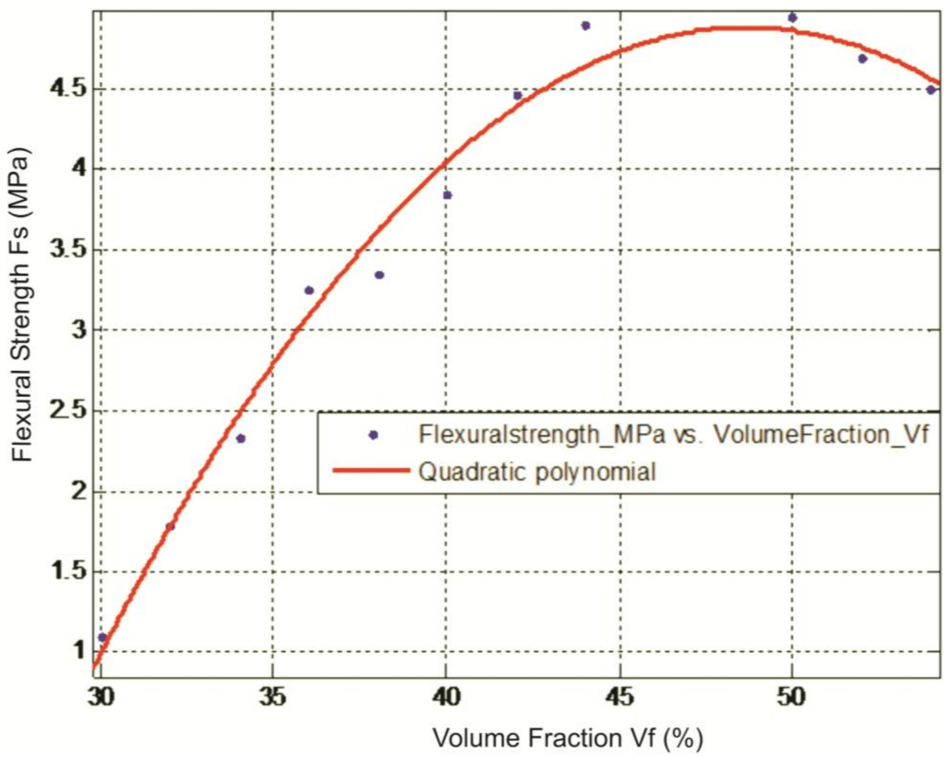

Fig. 3. Influence of volume fraction on the flexural strength of the composite

$$\frac{F_s}{F_{so}} = 1 - 0.0504V_f + 0.0005V_f^2 \quad (14)$$

From equation 14 therefore, the wood ash filler reinforcement for polyurethane matrix can be mathematically represented as

$$0.0504V_f + 0.0005V_f^2 \quad (15)$$

3.3 Weibull Modulus Parameter Determination and Reliability of Polyurethane Wood Ash Composites

50 Polyurethane wood ash Composites of [300/700/50] composition were further tested and the flexural strengths were obtained, the Weibull modulus/shape parameter was estimated by fitting the data to equation 9. The slope of the fitted data/Weibull modulus of 19.237 was determined using maximum and minimum points in the log scale. This Weibull modulus/shape parameter suggests that polyurethane wood ash composites has highly variable fracture strength, making it difficult to be used reliably in load-bearing applications [28], however more useful applications may include packaging and containerisation. Another characteristic of the distribution where the value of *m* has a distinct effect is the hazard rate, Fig. 4 shows Weibull distributions with m > 1 which is an indication of a failure rate that increases with time, also known as wear-out failures when compared with Fig. 1.

The Characteristics of Distribution Table 1 displays measures of the center and spread of the distribution. The mean time to failure (MTTF) and the median estimates are measures of the center of the distribution, whereas the standard deviation and the interquartile range (IQR) are measures of the spread of the distribution. The MTTF (1.2793) and the standard deviation (0.0823) are sensitive statistics because the tails in a skewed distribution and outliers significantly affect the values. The median (1.2906) and the IQR (0.1050) are resistant statistics because the tails in a skewed distribution and outliers do not significantly affect the values.

Table 1. Characteristics of distribution

	Estimate	Standard error	95.0% Normal CI	
			Lower	Upper
Mean(MTTF)	1.2793	0.0000118	1.27932	1.27937
Standard Deviation	0.0823	0.0000002	0.0823289	0.0823297
Median	1.2906	0.0000118	1.29061	1.29066
First Quartile(Q_1)	1.2329	0.0000117	1.23294	1.23299
Third Quartile(Q_3)	1.3379	0.0000119	1.33796	1.33801
Interquartile Range(IQR)	0.1050	0.0000003	0.105021	0.105022

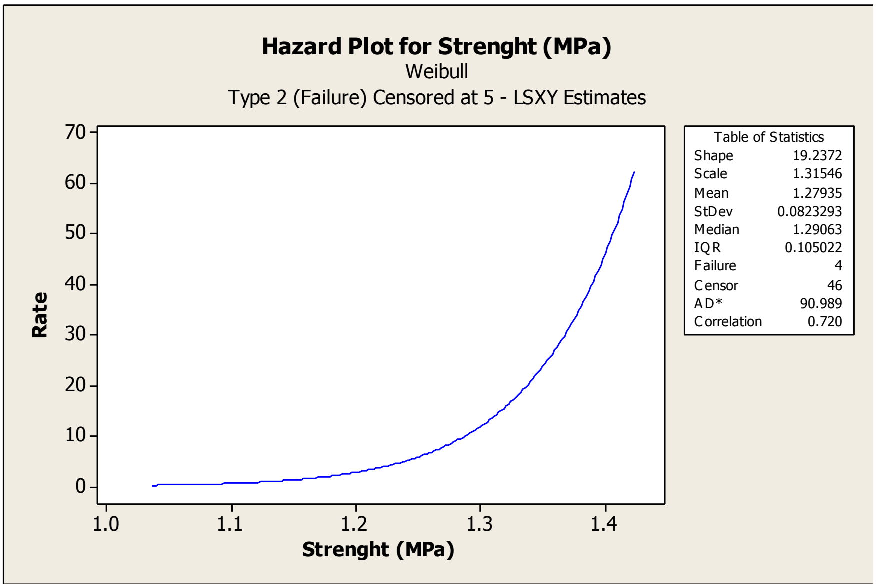

Fig. 4. Weibull hazard plot for strength of the composite

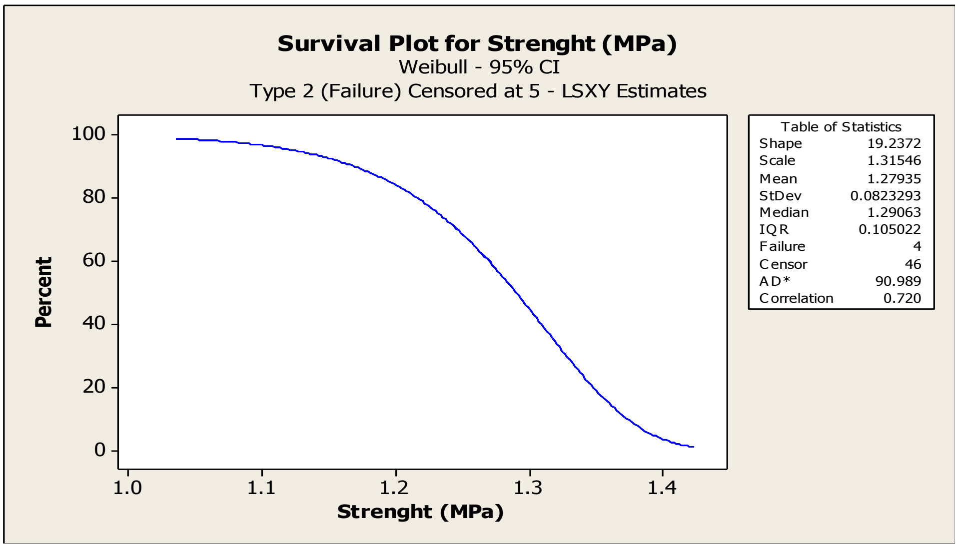

Fig. 5. Waibull survival plot for strength of the composite

The hazard function provides the likelihood of failure as a function of how long the material has lasted (the instantaneous failure rate at a particular time, t). The hazard plot shows the trend in the material failure rate over time. For this data, the hazard function is based on the Weibull distribution with shape = 19.2372 and scale = 1.3155. On this hazard plot, the hazard rate is increasing over time, which means that the materials are more likely to fail as they age. An increasing hazard happens in the later stages of a product's life, as in wear-out.

The survival plot depicts the probability that the material will survive until a particular time. Thus, the survival plot shows the reliability of the product over time. Fig. 5 showed maximum survival strength of 1.43MPa for polyurethane wood ash composite. As shown in the Fig. 5, the Weibull distribution reduces to the exponential distribution when the shape parameter p equals 1.

4. CONCLUSION

The following conclusions can be drawn from the results obtained in this research:

1. Varying carbonisation temperature resulted in different tensile and flexural values of the wood composite.
2. The tensile and flexural strengths of the composite increased with increasing fibre volume fraction.
3. The density of the composite decreases with the increase in fibre volume fraction.
4. The best improvement in the tensile and flexural strength of the wood composite samples is achieved when filled with 50% fibre volume fraction, having 300 μm particle size and carbonisation temperature of 700°C.
5. The density of the sample carbonised at 400°C recorded the highest density values, apparently in the entire fibre volume fraction with a highest value of 1.58 cm^3 at a reinforcement volume fraction of 30%. While the sample carbonised at 1000°C recorded the lowest value of 0.89 mm^3.
6. In all cases, carbonisation above 400°C showed improved mechanical properties as a result of increased carbon yield and reduction in tar and moisture content.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Tharanathan RN, Srinivasa PC, Ramesh MN. A process for production of biodegradable films from polysaccharides. Indian patent 0085/DEL/02; 2002.
2. Ihueze CC, Oluleye AE, Okafor CE, Obele CM, Abdulrahman J, Obuka S, Ajemba R. Development of plantain fibres for application in design of oil and gas product systems. Petroleum Technology Development Journal: An International Journal. 2017;7(1):32-51.
3. Dvorak WS. Worldview of *Gmelina arborea*: Opportunities and challenges. New Forests. 2004;28(2-3):111-126.

4. Roque RM, Fo MT. Wood density and fiber dimensions of *Gmelina arborea* in fast growth trees in Costa Rica: Relation to the growth rate. Forest Systems. 2007;16(3): 267-276.
5. Pathala D, Harini A, Hegde PL. A review on gambhari (*Gmelina arborea* Roxb.). Journal of Pharmacognosy and Phytochemistry. 2015;4(2).
6. Arora C, Tamrakar V. *Gmelina arborea*: Chemical constituents, pharmacological activities and applications. International Journal of Phytomedicine. 2017;9(4):528-542.
7. Iloabachie ICC, Obiorah SMO, Ezema IC, Henry VI, Chime OH. Effects of carbonization on the physical and mechanical properties of coconut shell particle reinforced polyester composite. International Journal of Research in Advanced Engineering and Technology. 2017;3(1):62-69.
8. Subyakto IB, Gustan P. Effects of Temperature and time of carbonization on the properties of bamboo (*Dendrocalamus asper*) Carbon. Wood Research Journal. 2012;3(2):68-73.
9. Ihueze CC, Obiafudo OJ, Okafor CE. Characterization of plantain fiber reinforced high density polyethylene composite for application in design of auto body fenders. Journal of Innovative Research in Engineering and Sciences. 2016;4(5):573-587.
10. Shakuntala O, Samir KA, Raghavendra G. Characterization and wear behavior of carbon black filled polymer composites. Procedia Materials Science. 3rd International Conference on Materials Processing and Characterization (ICMPC). 2014;6:468–475.
11. Malte P, Holger M. A note on reinforcement of polymer matrix composites using carbon residues derived from woody biomass. Journal of Composite Materials. 2010;44(15):20-10
12. Akanbi MN, Onuoha FN, Elele IN, Nwogu SC. Effect of carbonized saw dust on the mechanical properties of polyolefin plastics. Journal of Scientific Research & Reports. 2015;6(6):461-467.
13. Shuai CG, Yang X, He L, Yang SL. Study of mechanical property of polyurethane composites for vibration isolator. Materials Research Innovations. 2015;19(Sup5):S5-263.
14. Wang L, Ding W, Sun Y. Effect of different fiber materials on mechanical properties of polyurethane composites. In China: 2nd International Workshop on Materials Engineering and Computer Sciences (IWMECS 2015); 2015.
15. Hamilton AR, Thomsen OT, Madaleno LA, Jensen LR, Rauhe JCM, Pyrz R. Evaluation of the anisotropic mechanical properties of reinforced polyurethane foams. Composites Science and Technology. 2013;87:210-217.
16. Sair S, Oushabi A, Kammouni A, Tanane O, Abboud Y, El Bouari A. Mechanical and thermal conductivity properties of hemp fiber reinforced polyurethane composites. Case Studies in Construction Materials. 2018;8:203-212.
17. Subramaniyan SK, Mahzan S, bin Ghazali MI, Ismon M, Zaidi AMA. Mechanical behavior of polyurethane composite foams from kenaf fiber and recycled tire rubber particles. In Applied Mechanics and Materials. Trans Tech Publications. 2013;315:861-866.
18. Rozman HD, Yeo YS, Tay GS, Abubakar A. The mechanical and physical properties of polyurethane composites based on rice husk and polyethylene glycol. Polymer Testing. 2003;*22*(6):617-623.
19. Otto GP, Moisés MP, Carvalho G, Rinaldi AW, Garcia JC, Radovanovic E, Fávaro SL. Mechanical properties of a polyurethane hybrid composite with natural lignocellulosic fibers. Composites Part B: Engineering. 2017;110:459-465.
20. Marhoon II. Mechanical and physical properties of polyurethane composites reinforced with carbon black N990 particles. International Journal of Scientific & Technology Research. 2017;6(08):225-228.
21. Yusuf AK, Mamza PAP, Ahmed AS, Agunwa U. Physico-mechanical properties of rigid polyurethane foams synthesized from modified castor oil polyols. International Journal of Scientific and Research Publications. 2016;6(7):548-554.
22. Uzoma PC, Ogbobe O, Akanbi MN, Ezeh VO. Development of alternative extenders for flexible polyurethane foam production using bambara nut shell and corn chaff. The International Journal of Engineering And Science (IJES). 2015;4(7):21-24.
23. Azmi MA, Abdullah HZ, Idris MI. Properties of polyurethane foam/coconut coir fiber as a core material and as a sandwich

composites component. In IOP Conference Series: Materials Science and Engineering. IOP Publishing. 2013;50(1):012067.
24. Obidiegwu MU, Nwosu CT. Mechanical and flammability properties of low density polyethylene/Alstonia Boonei wood fiber composite. Asian J Nat Appl Sci. 2012;1(2):53-62.
25. Sumaila M, Ugheoke BI, Timon L, Oloyede T. A preliminary mechanical characterization of polyurethane filled with lignocellulosic material. Leonardo Journal of Sciences. 2006;1:159-166.
26. He J, Yap RCC, Wong SY, Li X. Polymer composites for intelligent food packaging. Journal of Molecular and Engineering Materials. 2015;3(01-02):1540005.
27. Mihindukulasuriya SDF, Lim LT. Nanotechnology development in food packaging: A review. Trends Food Sci. Technol. 2014;40:149.
28. Askeland DR, Fulay PP, Wright WJ. The Science and Engineering of Materials Sixth Edition. Canada: Cengage Learning; 2011.
29. Lamela MJ, Ferna´ndez A, Reiter H, Vin˜a J. Ana´lisis experimentaly estadı´stico del comportamiento a flexio´n dina´mica de laminados de fibra de carbono y resina epoxi. Actas del I Congreso Nacional de Materiales Compuestos, (in Spanish). 1995;335-40.
30. Barbero E, Fernández-Sáez J, Navarro C. Statistical analysis of the mechanical properties of composite materials. Composites Part B: Engineering. 2000;31(5):375-381.
31. Evans AG. Statistical aspects of cleavage fracture in steel. Metallurgical Transactions A. 1983;14:1349-55.
32. Beremin FM. A local criterion for cleavage fracture of a nuclear pressure vessel steel. Metallurgical Transactions A. 1983;14: 2277-87.
33. Ihueze CC, Achike MK, Okafor CE. Modelling and optimization of performance characteristics of coconut fibre particles reinforced high density polyethylene. Journal of Basic and Applied Research International. 2016;17(1):32-48.
34. Okafor CE, Godwin HC. Evaluation of compressive and energy adsorption characteristics of natural fiber reinforced composites (NFRC). World Journal of Engineering and Physical Sciences. 2014;2(3):036-048.
35. Ihueze CC, Okafor CE. Optimal design for flexural strength of plantain fibers reinforced polyester matrix. Journal of Innovative Research in Engineering and Sciences. 2014b;4(4):520-537.
36. Ihueze CC, Aguh PS. Optimization of tensile response of wood ash particles reinforced polypropylene (WARPP) for auto part design. SSRG International Journal of Mechanical Engineering (SSRG-IJME). 2015;2(9):10-21.
37. Ihueze CC, Aguh PS. Modeling and optimization of performance characteristics of wood ash particles reinforced PP resin (WARPP). Journal of Basic and Applied Research International. 2016;14(2):126-146. ISSN No.: 2395-3438 (Print), 2395-3446 (Online).
38. Aguh PS, Ejikeme IR. Design and evaluation of compressive strength of wood ash particles (Hardwood) reinforced polypropylene (WARPP) composite material for improved energy absorption in crash energy management. Saudi Journal of Engineering and Technology; 2017.
DOI: 10.21276/sjeat.2017.2.11.6
39. Jones RM. Mechanics of composite materials. 2nd Ed. Edwards Brothers, Ann Arbor; 1998.
40. Salih B. Effect of fillers on thermal and mechanical properties of polyurethane elastomer. Journal of Applied Polymer Science. 1988;68(7):1057-1065.
41. Zhuk AV, Knunyants NN, Oshmyan VG, Topolkaraev VA, Berlin AA. Debonding microprocesses and interfacial strength in particle-filled polymer materials. Journal of Materials Science. 1993;28(17):4995-5606.
DOI: 10.1007/BF00414247
42. Guth EJ. Theory of filler reinforcement. Journal of Applied Physics. 1945;16(1):20-25.
DOI: 10.1063/1.1707495

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