

Characteristics and Reliability of Polyurethane Wood Ash Composites

ABSTRACT (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

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 carbonization temperature, particle size and volume fraction. *Gmelina arborea* samples were sundried and carbonized at varied temperature (400, 700 & 1000°C), sieved to three particle sizes (75, 150 & 300µm) and 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 carbonization temperature resulted in different mechanical properties of the wood ash composites with the best improvement occurring at 50% volume fraction, having 300µm particle size at carbonization temperature of 700°C. However, decrease in the density of the composite was noticed when the fiber volume fraction increased. In all cases, carbonization 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 containerization.

Keywords: Reliability, Polyurethane, Wood Ash, Composites, Weibull distribution

1. INTRODUCTION (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)

There is a change in outlook occasioned by the development of ecological mindfulness and search for packaging and containerization 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 utilization 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 carbonization on the physic-mechanical properties of coconut shell/unsaturated polyester composite. Subyakto and Gustan [8] observed the effect of temperature and time of carbonization 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 characterization 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 carbonized 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 filler in polyurethane polymer are scarce in literature.

Food bundling and packaging advancements have continually developed over the years to beat challenges in the globalized purchaser showcase. Most of the materials (glass, metal, paper, composites and plastics) for sustenance packaging and containerization, 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] characterized 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 Weibull distribution also describes the fracture toughness of engineering materials where failure occurs by cleavage [31,32,30]. 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 characterization 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.

2. MATERIAL 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 carbonized sawdust weighing 200g was poured into the particle size analyzer '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 (75µm, 150µm, and 300µm) 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 casting 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

Specimens of size 20 x10x 5 mm³ was taken from the cast composite sheet. The weights of these samples were measured using a digital scale-precisa XB6200D weighing machine.

2.4 Tensile test procedure

Tensile test was carried out using a Testometric Universal Testing Machine according to ASTM D 638 using rectangular sheets of 200 mm x 5 mm x 10 mm. tests were done at ambient temperatures at a cross head speed of 50 mm/min giving rise to tensile strength, stress-strain, elongation at break and modulus

2.5 Flexural test procedure

Flexural test was performed using Testometric Universal Testing Machine according to ASTM D790. The composite samples were tested at a three-point bending scheme using a cross head speed of 50 mm/min. In each case, three samples were tested and average value reported.

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

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

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

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

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 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:

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

and

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

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



147 $\ln \sigma = m(\ln \sigma_0 - \ln F)$ (8)

148 the left-hand side of equation 8 by rewriting it as

149 $\ln \sigma = m(\ln \sigma_0 - \ln F)$ (9)

150 represents the characteristic stress level of the composite. In equation 3, when $1-F=1$ the

151 probability of survival becomes ≈ 0.37 . Therefore, σ_0 is the stress level for which the failure

152 probability is ≈ 0.63 or 63%. As the reliability probability of failure (F) goes down, the stress level to

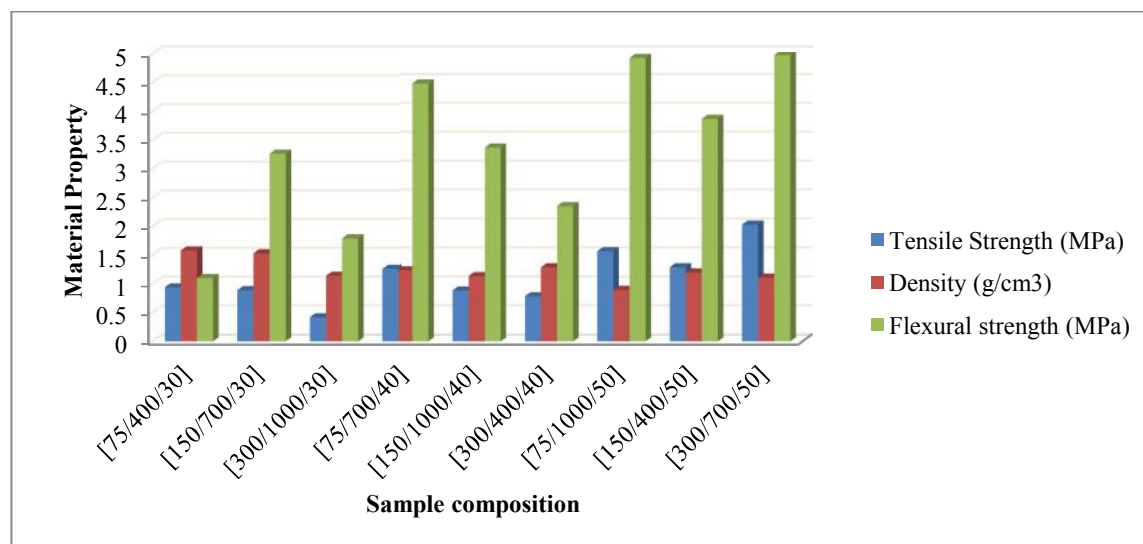
153 which the composite can be subjected (σ) also goes down [28].

3. RESULTS AND DISCUSSION

3.0. Initial characterization of Polyurethane wood ash Composites

159 The sample composition in the order of Particle size (μm)/Carbonization temperature ($^{\circ}\text{C}$)/Fiber

160 volume fraction (%) following Taguchi L9 orthogonal array is presented in the figure 1.



162

163

164 **Figure 1 Result of initial sample characterization**

166 Figure 1 above showed clearly that polyurethane composite has a significant flexural characteristics, the density of the composite as can be seen from the figure 1 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 carbonized @ 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.

173

174 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 carbonization temperature of 700°C. Generally, as could be seen in figure 1, the tensile strength of the composite samples increases with the increase in fiber volume 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.

181 From the figure 1, 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 figure 2 flexural strength of polyurethane wood ash composite increased with increase in volume fraction and attained maximum at 4.95MPa 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].

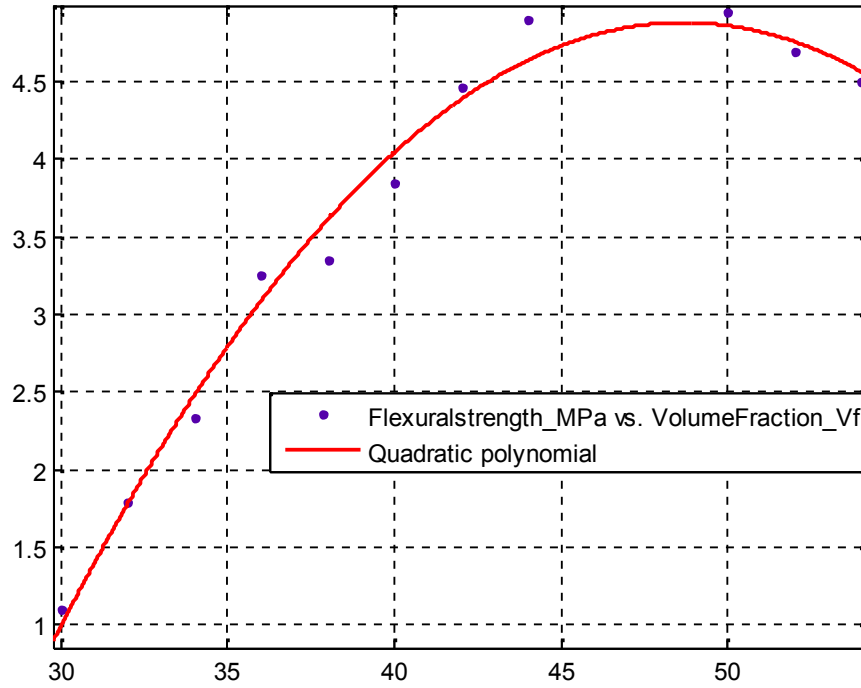


Figure 2. Influence of volume fraction on the flexural strength of the composite

$$F_s = -0.011V_f^2 + 1.084V_f - 21.51 \quad (10)$$

From equation 10,

$$F_s = -21.51 + 1.084V_f - 0.011V_f^2 \quad (11)$$

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

$$F_s = -21.51 \left[1 - 0.0504V_f + 0.0005V_f^2 \right] \quad (13)$$

Taking F_{s0} 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

$$\frac{F_s}{F_{s0}} = 1 - 0.0504V_f + 0.0005V_f^2 \quad (14)$$

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 as shown in table 1 were obtained, the Weibull modulus for the data can be estimated by fitting the data to equation 9.

Table 1: Table of cumulative probability of failure

I th Specimen	Flexural Strength	F(V)	$\ln\{\ln[1/[1-F(V)]]\}$	I th Specimen	Flexural Strength	F(V)	$\ln\{\ln[1/[1-F(V)]]\}$
1	2.97	0.02	-3.92194	26	1.47	0.51	-0.33834
2	4.24	0.04	-3.21874	27	1.92	0.53	-0.28267
3	4.09	0.06	-2.80305	28	4.07	0.55	-0.22774
4	1.05	0.08	-2.50497	29	2.5	0.57	-0.17342
5	4.78	0.10	-2.27124	30	3.51	0.59	-0.11957
6	1.5	0.12	-2.07814	31	3.8	0.61	-0.06604
7	3.19	0.14	-1.91301	32	1.47	0.63	-0.01269
8	3.14	0.16	-1.76828	33	4.96	0.65	0.040618
9	1.77	0.18	-1.63909	34	2.74	0.67	0.094048
10	4.38	0.20	-1.5221	35	3.52	0.69	0.147762
11	2.18	0.22	-1.41492	36	2.36	0.71	0.201941
12	1.86	0.24	-1.31578	37	4.37	0.73	0.256786
13	1.96	0.25	-1.22336	38	3.49	0.75	0.312528
14	3.96	0.27	-1.1366	39	2.3	0.76	0.369436
15	4.09	0.29	-1.05467	40	1.43	0.78	0.427833
16	4.91	0.31	-0.9769	41	4.79	0.80	0.488114
17	2.66	0.33	-0.90272	42	1.97	0.82	0.550777
18	1.12	0.35	-0.83168	43	2.95	0.84	0.616474
19	1.68	0.37	-0.76338	44	2.33	0.86	0.68608
20	2.25	0.39	-0.69748	45	2.54	0.88	0.760837
21	1.15	0.41	-0.63369	46	3.83	0.90	0.842596
22	1.12	0.43	-0.57176	47	3.54	0.92	0.934339
23	1.34	0.45	-0.51146	48	4.15	0.94	1.041412
24	2.52	0.47	-0.45257	49	4.09	0.96	1.175165
25	1.58	0.49	-0.39493	50	3.6	0.98	1.369104

The slope of the fitted data or Weibull modulus m was calculated as 1.64 by using maximum and minimum points in the log scale.

$$m = \frac{0.04 - (-2.50)}{\ln(4.96) - \ln(1.05)} = 1.64$$

This 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 [28], however more useful applications may include packaging and containerization etc

Table 2. Characteristics of Distribution

	Estimate	Standard Error	95.0% Normal CI	
			Lower	Upper
Mean(MTTF)	1.27935	0.0000118	1.27932	1.27937
Standard Deviation	0.0823293	0.0000002	0.0823289	0.0823297
Median	1.29063	0.0000118	1.29061	1.29066
First Quartile(Q ₁)	1.23296	0.0000117	1.23294	1.23299
Third Quartile(Q ₃)	1.33799	0.0000119	1.33796	1.33801
Interquartile Range(IQR)	0.105022	0.0000003	0.105021	0.105022

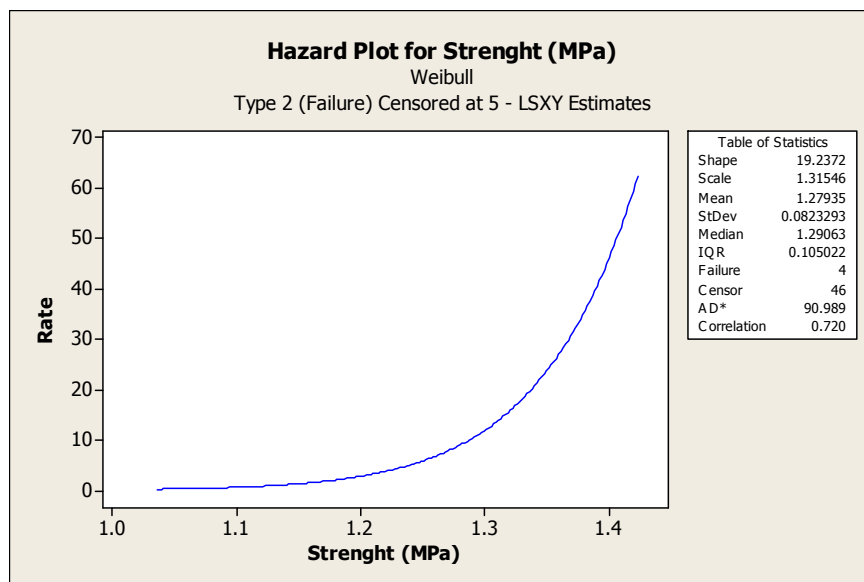


Figure 3. Waibull hazard plot for strength of the composite

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. Composite 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.

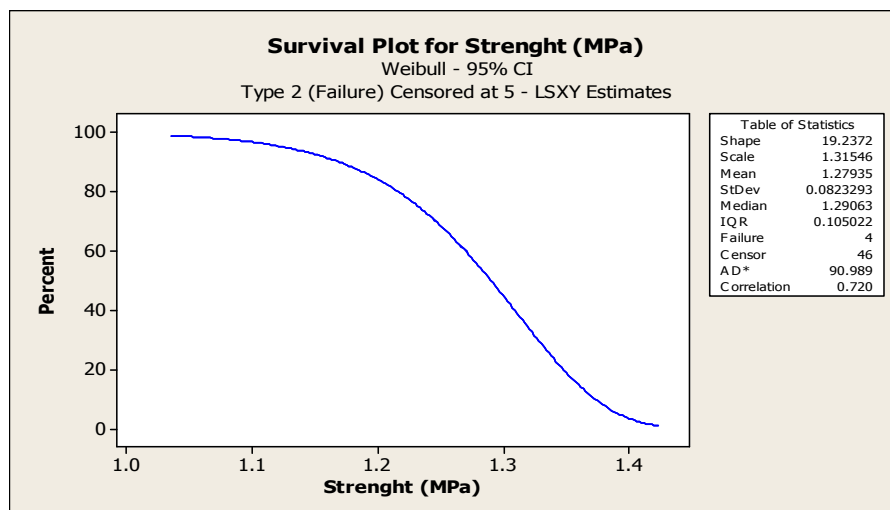


Figure 4. Waibull survival plot for strength of the composite

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. Figure 4 showed maximum survival strength of 1.43MPa for polyurethane wood ash composite.

4. CONCLUSION

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

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

REFERENCES

1. Tharanathan, R. N. Srinivasa P. C. and Ramesh M. N. (2002). A process for production of biodegradable films from polysaccharides. Indian patent 0085/DEL/02.
2. Ihueze, C.C., Oluleye, A. E., Okafor, C. E. Obele, C. M., Abdulrahman, J., Obuka S. and Ajemba R. (2017), Development of Plantain Fibres for Application in Design of Oil and Gas Product Systems. *Petroleum Technology Development Journal: An International Journal*. 7(1): 32-51.
3. Dvorak W.S., (2004). Worldview of Gmelina arborea: opportunities and challenges. *New Forests* 28(2-3), 111-126.
4. Roque, R. M., & Fo, M. T. (2007). Wood density and fiber dimensions of Gmelina arborea in fast growth trees in Costa Rica: relation to the growth rate. *Forest Systems*, 16(3), 267-276.
5. Pathala, D., Harini, A., & Hegde, P. L. (2015). A review on gambhari (Gmelina arborea Roxb.). *Journal of Pharmacognosy and Phytochemistry*, 4(2).
6. Arora, C., & Tamrakar, V. (2017). Gmelina arborea: chemical constituents, pharmacological activities and applications. *International Journal of Phytomedicine*, 9(4), 528-542.
7. Iloabachie, I.C.C, Obiorah, S.M.O, Ezema, I.C, Henry, V.I and Chime O.H. (2017). 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*. 3(1): 62-69.
8. Subyakto, I. B and Gustan P. (2012). Effects of Temperature and Time of Carbonization on the Properties of Bamboo (Dendrocalamus asper) Carbon. *Wood Research Journal*. 3(2): 68-73.
9. Ihueze, C. C, Obiafudo, O. J, Okafor C. E. (2016). 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* 4(5): 573-587.
10. Shakuntala, O., Samir K. A. and Raghavendra G. (2014). Characterization and Wear Behavior of Carbon Black Filled Polymer Composites. *Procedia Materials Science* 6 468 – 475. 3rd International Conference on Materials Processing and Characterization (ICMPC).
11. Malte, P. and Holger, M. (2010). A Note on Reinforcement of Polymer Matrix Composites Using Carbon Residues Derived From Woody Biomass. *Journal of Composite Materials*. 44(15): 20-10

- 305 12. Akanbi, M. N., Onuoha, F. N., Elele, I. N and Nwogu, S. C. (2015). Effect of Carbonized Saw
306 Dust on the Mechanical Properties of Polyolefin Plastics. *Journal of Scientific Research &*
307 *Reports* 6(6): 461-467.
- 308 13. Shuai, C. G., Yang, X., He, L., & Yang, S. L. (2015). Study of mechanical property of
309 polyurethane composites for vibration isolator. *Materials Research Innovations*, 19(sup5), S5-
310 263.
- 311 14. Wang, L., Ding, W., & Sun, Y. (2015). Effect of different fiber materials on mechanical
312 properties of polyurethane composites. In *China: 2nd International Workshop on Materials*
313 *Engineering and Computer Sciences (IWMECS 2015)*.
- 314 15. Hamilton, A. R., Thomsen, O. T., Madaleno, L. A., Jensen, L. R., Rauhe, J. C. M., & Pyrz, R.
315 (2013). Evaluation of the anisotropic mechanical properties of reinforced polyurethane foams.
316 *Composites Science and Technology*, 87, 210-217.
- 317 16. Sair, S., Oushabi, A., Kammouni, A., Tanane, O., Abboud, Y., & El Bouari, A. (2018).
318 Mechanical and thermal conductivity properties of hemp fiber reinforced polyurethane
319 composites. *Case studies in construction materials*, 8, 203-212.
- 320 17. Subramaniyan, S. K., Mahzan, S., bin Ghazali, M. I., Ismon, M., & Zaidi, A. M. A. (2013).
321 Mechanical behavior of polyurethane composite foams from kenaf fiber and recycled tire
322 rubber particles. In *Applied Mechanics and Materials* (Vol. 315, pp. 861-866). Trans Tech
323 Publications.
- 324 18. Rozman, H. D., Yeo, Y. S., Tay, G. S., & Abubakar, A. (2003). The mechanical and physical
325 properties of polyurethane composites based on rice husk and polyethylene glycol. *Polymer*
326 *Testing*, 22(6), 617-623.
- 327 19. Otto, G. P., Moisés, M. P., Carvalho, G., Rinaldi, A. W., Garcia, J. C., Radovanovic, E., &
328 Fávoro, S. L. (2017). Mechanical properties of a polyurethane hybrid composite with natural
329 lignocellulosic fibers. *Composites Part B: Engineering*, 110, 459-465.
- 330 20. Marhoon, I. I. (2017). Mechanical and Physical Properties of Polyurethane Composites
331 Reinforced With Carbon Black N990 Particles. *International Journal of Scientific &*
332 *Technology Research*, 6(08), 225-228.
- 333 21. Yusuf, A. K., Mamza, P. A. P., Ahmed, A. S., & Agunwa, U. (2016). Physico-Mechanical
334 Properties of Rigid Polyurethane Foams Synthesized From Modified Castor Oil Polyols.
335 *International journal of scientific and research publications*, 6(7), 548-554.
- 336 22. Uzoma, P. C., Ogbobe, O., Akanbi, M. N., & Ezech, V. O. (2015). Development of Alternative
337 Extenders for Flexible Polyurethane Foam Production Using Bambara Nut Shell and Corn
338 Chaff. *The International Journal Of Engineering And Science (IJES)* 4(7); 21-24.
- 339 23. Azmi, M. A., Abdullah, H. Z., & Idris, M. I. (2013). Properties of Polyurethane Foam/Coconut
340 Coir Fiber as a Core Material and as a Sandwich Composites Component. In *IOP Conference*
341 *Series: Materials Science and Engineering* (Vol. 50, No. 1, p. 012067). IOP Publishing.
- 342 24. Obidiegwu, M. U., & Nwosu, C. T. (2012). Mechanical and flammability properties of low
343 density polyethylene/Alstonia Boonei wood fiber composite. *Asian J Nat Appl Sci*, 1(2), 53-62.
- 344 25. Sumaila, M., Ugheoke, B. I., Timon, L., & Oloyede, T. (2006). A Preliminary mechanical
345 characterization of polyurethane filled with lignocellulosic material. *Leonardo Journal of*
346 *Sciences*, 1, 159-166.
- 347 26. He, J., Yap, R. C. C., Wong, S. Y., & Li, X. (2015). Polymer composites for intelligent food
348 packaging. *Journal of Molecular and Engineering Materials*, 3(01n02), 1540005.

- 349 27. Mihindikulasuriya S. D. F. and L. T. Lim, (2014). Nanotechnology development in food
350 packaging: A review. *Trends Food Sci. Technol.* 40, 149
- 351 28. Askeland, D. R., Fulay P. P. & Wright, W. J. (2011). *The Science and Engineering of*
352 *Materials* Sixth Edition. Canada: Cengage Learning.
- 353 29. Lamela MJ, Fernández A, Reiter H, Vinã J. (1995) Ana´lisis experimental y estadístico del
354 comportamiento a flexio´n dina´mica de laminados de fibra de carbono y resina epoxi. *Actas*
355 *del I Congreso Nacional de Materiales Compuestos*, (in Spanish). p. 335-40.
- 356 30. Barbero, E., Fernandez-Saez, J., & Navarro, C. (2000). Statistical analysis of the mechanical
357 properties of composite materials. *Composites Part B: Engineering*, 31(5), 375-381.
- 358 31. Evans AG. (1983). Statistical aspects of cleavage fracture in steel. *Metallurgical Transactions*
359 *A*;14:1349-55.
- 360 32. Beremin FM. (1983). A local criterion for cleavage fracture of a nuclear pressure vessel steel.
361 *Metallurgical Transactions A*;14:2277-87.
- 362 33. Ihueze, C. C. Achike M. K. and Okafor C. E. (2016). Modelling And Optimization Of
363 Performance Characteristics Of Coconut Fibre Particles Reinforced High Density
364 Polyethylene. *Journal of Basic and Applied Research International*. 17(1): 32-48, 2016
- 365 34. Okafor C. E and Godwin H. C (2014). Evaluation of Compressive and Energy Adsorption
366 Characteristics of Natural Fiber Reinforced Composites (NFRFC). *World Journal of*
367 *Engineering and physical Sciences* 2 (3) pp. 036-048.
- 368 35. Ihueze C. C. and Okafor, C. E (2014b). Optimal Design for Flexural Strength of Plantain
369 Fibers Reinforced Polyester Matrix. *Journal of Innovative Research in Engineering and*
370 *Sciences* 4(4), pp. 520-537.
- 371 36. Ihueze, C. C. and Aguh P. S (2015) Optimization of Tensile Response of Wood Ash Particles
372 Reinforced Polypropylene (WARPP) for Auto Part Design. *SSRG International Journal of*
373 *Mechanical Engineering (SSRG-IJME)*, 2(9); 10-21.
- 374 37. Ihueze, C. C. and Aguh P. S (2016). Modeling and Optimization of Performance
375 Characteristics of Wood Ash Particles Reinforced PP Resin (WARPP). *Journal of Basic and*
376 *Applied Research International*, ISSN No. : 2395-3438 (Print), 2395-3446 (Online), 14(2):
377 126-146
- 378 38. Aguh P. S & Ejikeme I. R. (2017) Design and Evaluation of Compressive Strength of Wood
379 Ash Particles (Hardwood) Reinforced Polypropylene (WARPP) Composite Material for
380 Improved Energy Absorption in Crash Energy Management. *Saudi Journal of Engineering*
381 *and Technology*. DOI:10.21276/sjeat.2017.2.11.6
- 382 39. Jones R. M. 1998. *Mechanics of composite materials*. 2nd Ed. Edwards Brothers, Ann Arbor
- 383 40. Salih, B. (1988). Effect of Fillers on Thermal and Mechanical Properties of Polyurethane
384 Elastomer. *Journal of Applied Polymer Science*. 68 (7): 1057-1065
- 385 41. Zhuk, A. V. Knunyants, N. N. Oshmyan, V. G. Topolkaraev V. A. and Berlin, A. A. (1993).
386 "Debonding Microprocesses and Interfacial Strength in Particle-Filled Polymer Materials,"
387 *Journal of Materials Science*, Vol. 28, No. 17, , pp. 4995-5606. [doi:10.1007/BF00414247](https://doi.org/10.1007/BF00414247)
- 388 42. Guth, E. J. "Theory of Filler Reinforcement," *Journal of Applied Physics*, Vol. 16, No. 1, 1945,
389 pp. 20-25. [doi:10.1063/1.1707495](https://doi.org/10.1063/1.1707495)