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FABRICATION OF EPOXY BASE PARTICULATE COMPOSITES FILLED WITH AFRICAN MESQUITE PODS FOR CEILING BOARD APPLICATION

***Jibril, A., Ishiaku, U.S., Musa, M.B., Giwa, A. and Yusuf, L.O.**
Department of Polymer and Textile Engineering, Ahmadu Bello University, Zaria.
*Correspondence: +2348036539006/Aliyujibril90@gmail.com

ABSTRACT

The extensive deforestation of African mesquite trees and the significant waste produced due to their perceived economic value have spurred research into using their solid waste in construction applications. This study investigates the utilization of African mesquite waste pods as a filler in epoxy composites. Composites were prepared using hand mixing with filler particle sizes of 100 µm, 200 µm, and 300 µm, and filler loadings of 5, 10, 15, 20, 25, 30, 35, and 40 wt%. The composites were assessed for water absorption, tensile strength, hardness, and morphological properties in accordance with ASTM standards. Results demonstrated that African mesquite pod/epoxy resin (AMP/ER) composites exhibited low water absorption with reduced filler content and particle size. Tensile strength reached a peak at 10 wt% filler loading (37.55 MPa), whilst tensile modulus increased with higher filler content but decreased with larger particle sizes, in contrast to elongation, which improved with lower filler content and smaller sizes. Hardness increased with both filler loading and particle size, achieving a maximum of 82.83 Hv at 40 wt% with 100 µm particles. SEM analysis of fractured tensile specimens revealed uniform particle distribution at lower filler content (10 wt%), whereas higher loadings displayed agglomeration and interfacial gaps, explaining the enhanced mechanical properties at lower dosages. These AMP/ER composites possess suitable properties for ceiling board production in building construction.

Keywords: *Epoxy; African Mesquite Pod; Water absorption, tensile, hardness and SEM*

1. INTRODUCTION

A composite is a material consisting of two or more insoluble materials (Figure 1), which are combined to create a useful engineering material having some properties not obtained by the constituents taken separately [1].

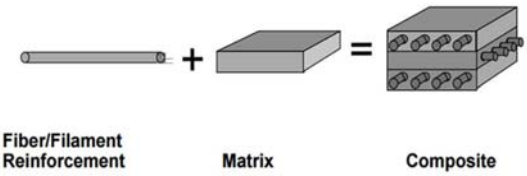

Figure 1: Composite material

Wood-Plastic Composites (WPCs) are materials made by incorporating lignocellulosic materials into polymer matrices in varying sizes and proportions [2]. There has been growing interest in WPCs over the past few decades due to their numerous advantages, including low cost, low density, high toughness, good thermal properties, ease of processing, and biodegradability, compared to traditional reinforcing materials such as glass fibre, animal bones, and shells [3][4].

African mesquite (*Prosopis Africana*) tree, whose waste pods are shown in Plate I, is one of the several sources of lignocellulosic filler applicable in WPCs. It is widely utilized across Nigeria and beyond due to its rich nutritional profile and industrial applications [5][6].

However, a significant environmental challenge arises as the pods and shells of these trees are largely discarded as waste or openly burned, leading to pollution and atmospheric degradation. Despite extensive research on agricultural residues for composite fabrication, there are very scanty reports on the use of African Mesquite Pods (AMP) as fillers in composite materials [7].

Plate I: (a) Pods, (b) crushed pods, and (c) seeds, of African Mesquite.

In an attempt to bridge this gap as well as to address the current challenges of high-water absorption in commercial ceiling boards, the present study focuses on the development of particulate composites by incorporating AMP fillers in varying dosages and particle sizes into an epoxy matrix with a specific aim of exploring its application in building construction.

MATERIALS AND METHODS

Materials

The African Mesquite Pods (AMP) were collected from Agbeji-Anyigba, Dekina local government in Kogi state (Nigeria). The glass moulds used with dimensions of 200 x 150 x 5 (mm) were fabricated from the Glass Technology Departmental workshop at Ahmadu Bello University in Zaria. Standard liquid epoxy resin with an approximate density of 1.17 g/cm^3 and a cycloaliphatic amine type hardener was obtained from Fanor Agency Limited in Ojota Market, Lagos, Nigeria. The equipment used includes: pulveriser (Savona equipment), Endecotts EFL 2000/1 sieve machine - Gemini BV, Standard test sieves (Associated Scientific and Engineering Works).

Method

The pods of African mesquite were cleaned and partially crushed using a pulveriser to break them open to separate the seeds from the pods. The pods were further pulverised to finer powder and finally sieved to 100, 200, and 300µm particle size. The samples were individually stored in clean airtight containers to avoid moisture absorption before use.

The composites were fabricated by the hand mixing method according to the method reported by Jibril *et al.* [8]. After preparing the mould (cleaning, fitting with foil paper and releasing agent), a pre-weighed quantity of the matrix and AMP filler were mixed together until uniformity is achieved through proper and careful stirring. The mixture was then cast into and allowed to uniformly spread over the mould, followed by a slight vibration to help rid the entrapped air and promote particle matrix bonding. This was allowed to cure at room temperature for 24 hours to achieve crosslinking of the matrix, after which the composite was removed, trimmed and properly labelled as AMP/ER composite.

Water absorption test

The water absorption test was carried out according to ASTM D570. The samples were conditioned in an oven at 40 °C for 24 hours. They were then placed inside desiccators for 24 hours and weighed (W_1) using an analytical balance. Each of the weighed samples was then placed inside a plastic container with distilled water. These samples were repeatedly removed, carefully wiped and weighed (W_2) after every 24 hours at specified times for four (4) weeks. The percentage of water absorbed by the composites was determined using the equation below:

$$Water\ Absorption\ (\%) = \frac{W_2 - W_1}{W_1} \times 100$$

Tensile test

The test was conducted on the dog-bone shaped samples with dimensions 100 mm x 20 mm x 5 mm and 50 mm gauge lengths in accordance with ASTM D638 standard test method using a Tensile strength testing machine (Model TM2101-T7, China). Each test was run in triplicate, and the mean values were considered. Tensile strength, tensile modulus and elongation at break properties were obtained from this test.

Hardness test

The hardness test was conducted in accordance with ASTM E384 standard test method using Vickers Hardness Tester (MV1-PC, Mh-vCM.07/2012-1329, China) with a maximum load capacity of 0.3 kgf (100 HV)

by mounting a specimen with dimension 30 mm × 10 mm × 5 mm on the specimen compartment with its smooth surface preserved while the indentation point was focused. Triplicate tests were conducted, and the results were averaged for analysis.

Morphological study

The morphological features of the tensile fractured surface of the composites were studied in accordance with ASTM E986-04 standard test method using Thermo Fisher Prisma E SEM operated at 10 kV and a magnification of 100×. A sizable portion of each specimen was sputter-coated with a thin layer of gold to improve surface conductivity, enhance image quality by preventing electrostatic discharge.

RESULTS AND DISCUSSION

Water Absorption of AMP/ER Composite

Figure 2(a-c) shows that an increase in filler loading of the AMP/ER composite significantly enhanced the water absorption. The results showed that the 5 wt% loading exhibited the lowest equilibrium water uptake across all particle sizes. Specifically, the 100 µm composite achieved an equilibrium water absorption of 1.51% after 10 days, whereas the 200 µm and 300 µm composites reached equilibrium absorptions of 1.62% (after 10 days) and 1.78% % (after 15 days), respectively. In contrast, the 40 wt% loading resulted in significantly higher water absorption, with equilibrium absorptions of 8.31%, 8.33%, and 8.47% for the 100 µm, 200 µm, and 300 µm composites, respectively. Notably, the 300 µm composite at 40 wt% exhibited the highest water absorption among all formulations.

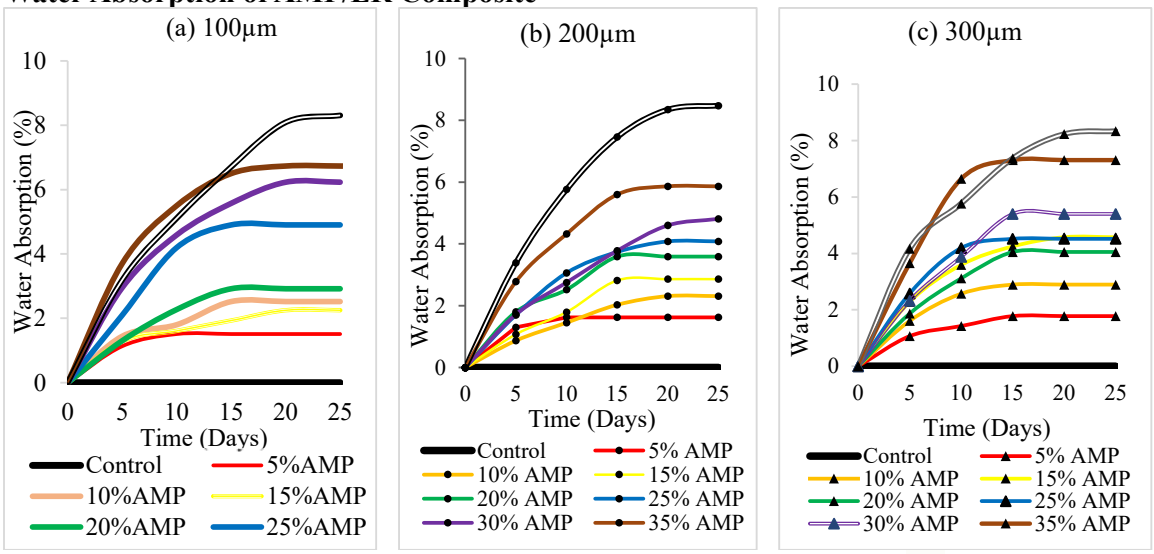

Figure 2(a-c): Effect of filler loading and particle size on water absorption of AMP/ER composites

These results clearly demonstrate that increasing filler loading as well as particle size both enhance the water absorption capacity of the composite, as the highest water uptakes were consistently observed at 40 wt% filler loading with 300 µm size. The hydrophilic nature of the lignocellulosic AMP filler contributes to moisture uptake since the cellulose and hemicellulose in natural filler contain numerous hydroxyl (-OH) groups, which readily form hydrogen bonds with water molecules. As the filler content increases, more of these polar groups are introduced into the composite, thereby increasing the number of active sites for water adsorption [9]. Also, the poor dispersion at high concentrations can cause agglomeration and defects that further promote moisture ingress [10]. On the other hand, particle size variation gave an insignificant impact on water uptake; nevertheless, the slight enhancement in water uptake with larger particles can be linked to their ability to create more binding sites, like voids and matrix flaws, for water molecules to attach due to their increased surface area [10].

Tensile strength of AMP/ER composites

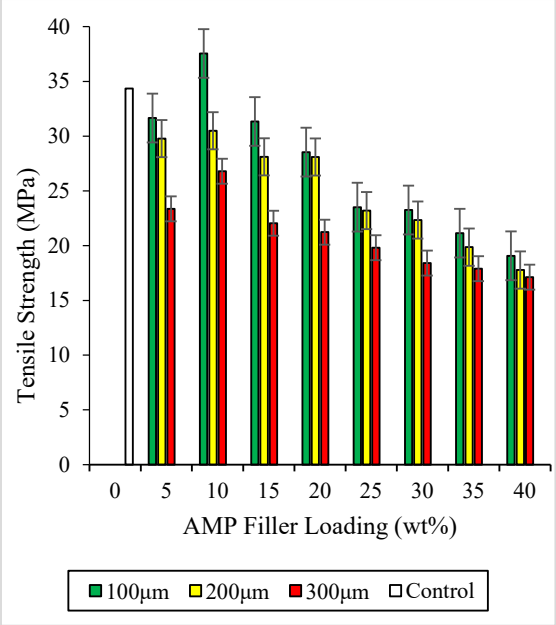

Figure 3: Effect of filler loading and particle size on tensile strength of AMP/ER composites

Figure 3 indicates that the tensile strength of AMP/ER composites initially rises with the increased filler loading up to a peak of 37.55 MPa at 10 wt% filler loading. As the filler loading exceeded 10 wt%, a steady decline in the composite's tensile strength was observed. The early rise in tensile strength for filler loading increment is in accordance with some reports [3][11][12].

The improvement in tensile strength observed might be due to the effective stress transfer that occurs between the epoxy matrix and the dispersed cellulose fillers at low filler loadings, causing the cellulose fillers to behave as reinforcement and therefore improving the mechanical properties of the composite as a whole [12]. The decline in tensile strength beyond 10 wt% can be ascribed to the phenomenon of agglomeration and low matrix-filler interaction [13][14]. On the other hand, the reduction in the particle sizes was found to enhance the tensile strength of AMP/ER composites. According to Kolawole *et al*., the reduction in particle size is likely to increase the surface area of the resin for interaction, hence enhancing the stress transfer process and consequently resulting in tensile strength increase [15].

Tensile modulus of AMP/ER composites

Figure 4 reveals that the tensile modulus of AMP/ER increased with an increase in filler loading and decreased with particle size. Therefore, the peak stiffness of 405 MPa was obtained at 40 wt% with the finest particle (100 µm), while the least stiffness of 303 MPa was obtained at 5 wt% with 300 µm

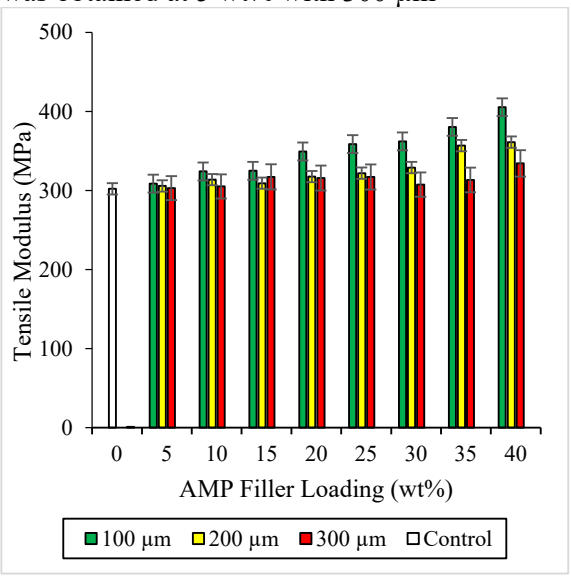

Figure 4: Effect of filler loading and particle size on tensile modulus of AMP/ER composites

Similar trends were reported by other researchers [3][16]. The increase in tensile modulus can be credited to the restriction in mobility of polymer chains as the filler content rises [17] because with more particles within the polymer matrix, the polymer chains are less able to move and flex under stress, thereby enhancing its elastic modulus.

Also, as the particle size of the cellulosic filler decreases, the elastic modulus of the resulting composite tends to increase because, given their higher surface area to volume ratio, smaller particles can adhere to the epoxy resin more effectively thus enhancing the interfacial adhesion to improve the stress transfer from the matrix to the filler which give rise to higher elastic modulus [15].

Elongation at break of AMP/ER composites

Figure 5 depicts a decreasing trend in the percentage elongation as filler loading increases, as obtained by Danladi and Shu'aib (2014)[18].

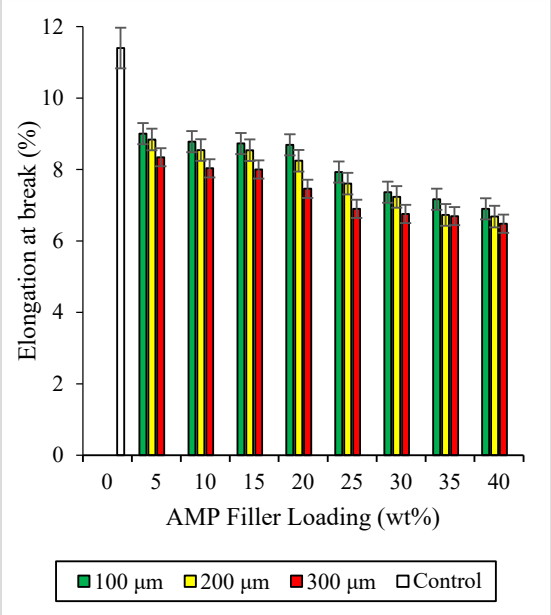

Figure 5: Effect of filler loading and particle size on elongation at break of AMP/ER composites

Due to the brittle nature of cellulose fillers, the more the quantity of filler in the matrix, the more brittle the resulting composite becomes, thus hampering its ability to deform adequately before breaking [19]. Likewise, Nagarajan *et al.* (2020) credited the decrease in percentage elongation at break with an increase in filler loading to the increase in rigidity of the composite due to restriction in mobility and deformability of the polymer matrix [20].

Elongation was also found to decrease with particle sizes; thus, the peak elongations were all obtained with 100 µm particles, while the least elongations were recorded with 300 µm particle sizes. Umaru *et al.* and Kolawole *et al.* reported a similar trend [11][15]. The poor distribution of larger particles consequently yields poor bonding between the fillers and the matrix, which may be the cause of the decline in percentage elongation at break with an increase in particle size [12].

Hardness of AMP/ER composites

Figure 6 shows that the hardness of the composite was far beyond that of the unfilled epoxy sample, which could be attributed to the comparatively higher hardness of the fillers over the epoxy matrix [21].

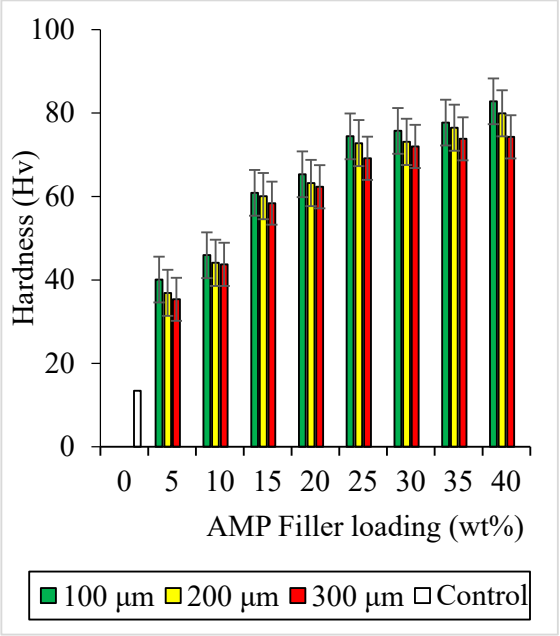

Figure 6: Effect of filler loading and particle size on the hardness of AMP/ER composite

Also, it was observed that the higher the percentage of the fillers incorporated, the harder the material and the more rigid it becomes; thus, the minimum hardness (37 Hv) was recorded at 5 wt% filler loading while the peak hardness (80 Hv) was obtained at 40 wt% filler dosage. The increase in hardness may also be attributed to good interfacial adhesion and bond strength between fillers and the epoxy matrix, respectively [22] as well as uniform dispersion of the AMP fillers in the structure of the composites [23].

On the other hand, the hardness was found to increase with a decrease in filler particle sizes; thus, the peak hardness was revealed by 100 µm particles, while the least hardness was recorded by 300 µm. Similar trends were also reported in some research findings [24]. According to Awad *et al.* (2019), smaller particles display higher resistance to indentation as they tend to adhere and disperse more effectively than larger particles that experience poor distribution either due to their reduced surface area or due to agglomeration, which deteriorates their hardness properties [24].

Morphological characteristics of AMP/ER composite

The dispersed phase distribution of the tensile fractured surface of the unfilled epoxy sample,

as well as AMP/ER composite, are revealed by the SEM images in Plate II (a-c).

The smooth surface in Plate IIa might be due to the absence of filler in the matrix, which hinders effective stress redistribution, resulting in straight and clean fracture lines, which are indicative of a brittle fracture [25]. At 10 wt% filler loading (IIb), the SEM images indicate very uniform dispersion of lignocellulosic particles within the epoxy matrix. The sufficient interfacial adhesion of filler to the matrix enables effective stress transfer and reduced void formation [26].

On the other hand, AMP/ER with 40 wt% filler loading displayed some filler agglomeration (IIc), which can be attributed to high filler content exceeding the wetting capacity of the matrix. This outcome confirms the reason for the enhancement of tensile strength at lower filler dosage (10 wt%) as opposed to the 40 wt% filler-dosed composite.

CONCLUSION

The use of waste AMP as a composite filler has been successfully achieved. The following conclusion can be drawn:

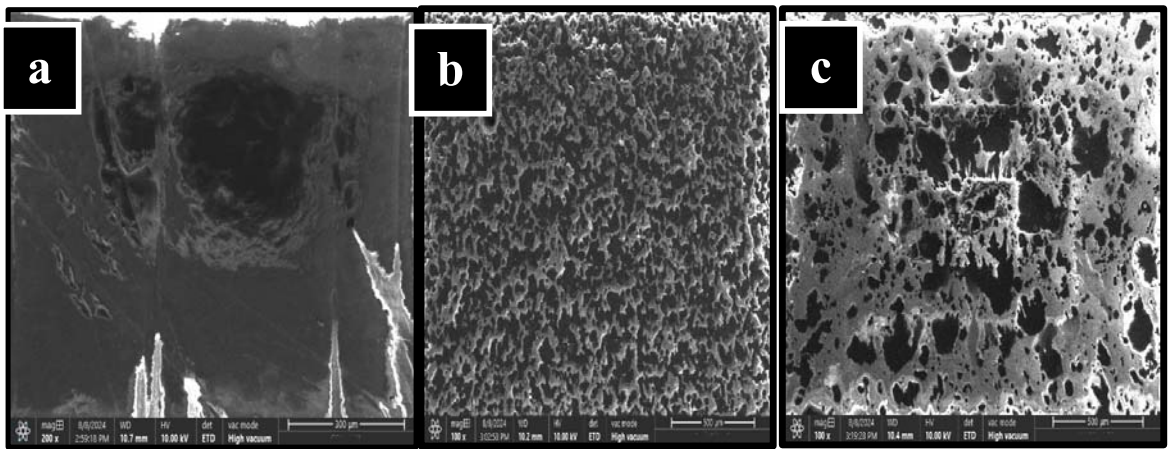

Plate II: SEM micrograph of tensile fractured surface of AMP/ER composite at 100× magnification showing effect of filler loading; (a) control sample (b) 10 wt% AMP/ER (c) 40 wt% AMP/ER

AMP is a good reinforcement for low-cost composite materials because of their improved mechanical properties. Lower particle-sized filler (100) proved to be more favourable because water absorption as well as all mechanical properties studied were better with decreasing particle size.

Harnessing the AMP in composite fabrication will not only significantly reduce the carbon footprints but also assist with a healthier environment. Their non-toxicity, low cost, ready availability and ease of processing will encourage large-scale commercialization in non-load bearing applications such as ceiling board products for building construction.

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