






ORIGINAL RESEARCH ARTICLE

Development of Epoxy-Based Particulate Composite Cladding from *Prosopis africana* PodsAliyu Jibril*¹, Umaru Semo Ishiaku¹, Muhammad Musa Bukhari¹, Abdurraheem Giwa¹,
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ABSTRACT

The high maintenance and procurement costs of wood wall claddings in building construction have created a need for an alternative material that is more durable, stiffer, tougher, and thermally stable. To develop a cost-effective, lightweight, and eco-friendly cladding material, this study aims to fabricate an epoxy-based composite using lignocellulosic fillers, such as waste pods from the iron tree, with varying filler dosages between 10% and 40% weight and particle sizes between 100 μm and 200 μm . The composites were tested for flexural, impact, and thermal properties according to ASTM standards. Results showed that the composites achieved a peak bending strength of 40.5 MPa with the finest particle sizes (100 μm) and a 10 wt% filler dosage. The highest stiffness of 2.58 GPa was observed at the maximum filler dosage. Impact resistance decreased with increased filler dosage and particle size, while thermal stability also declined as filler dosage increased. Comparing these composite properties with those of commercial cladding revealed that AMP/ER composites could be suitable for interior wall cladding applications in building construction.

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INTRODUCTION

The Iron tree (*Prosopis africana*), commonly known as African mesquite, is a popular deciduous perennial legume (family: Fabaceae) tree species that grows abundantly across Nigeria and Africa at large (Odetoyen & Adeoye, 2022). A study by Oluwafemi et al. (2021) details the numerous significant potentials of the Iron plant's seeds, leaves, stems, and roots, which range from therapeutic to nutritional values. Due to its well-recognised economic advantages, the plant is frequently and continuously explored, with residues from the pods often discarded as waste. This research aims to investigate the possibility of converting these waste pods into useful structural materials, such as wall cladding panels for interior building walls.

Wall cladding involves applying one material over another to create a protective layer. In construction, it helps improve thermal insulation, weather resistance, and visual appeal of buildings, as well as serving as a noise control barrier that limits sound transmission into and out of the structure (Kolan & Purandare, 2019).

Problems of high cost plague commercial claddings due to the expensive materials used in their manufacture (Kolan & Purandare, 2019). Their heavy weight compounds this

problem. However, the drawback is currently undergoing a sweeping change as companies now explore lignocellulosic materials as fillers to fabricate composites intended for use as cladding. One successful approach is a commercial composite material GF (made of HDPE and bamboo wood fibre), which is popularly marketed as Chinese-made cladding material (Decorative Sustainable Materials, n.d.) (Plate 1). This study, therefore, seeks to combine the advantages of high specific strength and hydrophobicity of epoxy with the lightweight nature of lignocellulosic fillers (pods of iron tree, as shown in Figure 1), alongside their ready availability (as waste residue) and ease of processing, to fabricate a lightweight material for composite cladding applications. The success of this study will enhance the economic value of the plant species, discourage deforestation by utilising its pods instead of timber, reduce carbon footprints, and replace current synthetic cladding materials with more eco-friendly composite options.

MATERIALS AND METHOD

Materials

The pods from the iron tree were collected from Agbeji-Anyigba, Dekina local government in Kogi state (Nigeria)

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during the dry season (January, 2023). Glass moulds of dimensions 200mm x 150mm x 5mm were used. A standard, medium-viscosity liquid Bisphenol-A epoxy resin (DOCURE YD-128 with a density of 1.17 g/cm³) and a cycloaliphatic amine hardener (DOCURE KH-816 with viscosity between 300 - 500 cps), both produced by Kukdo Chemical, were used. Some of the equipment used includes: pulveriser (Savona equipment), Endecotts EFL 2000/1 sieve machine - Gemini BV, Standard test sieves (Associated Scientific and Engineering Works), Flexural Strength testing Machine (Model TM2101-T7, China), Charpy impact Testing Machine (Norwood Instrument Cat Nr.412-07-15269C), Thermogravimetric Analyzer (Perkin Elmer TGA4000, Perkin Elmer Inc., USA).



Figure 1: African Mesquite (Iron tree) pod (*Prosopis Africana*, n.d.).



Plate I: GF commercial composite claddings made from HDPE and bamboo wood fibre (Decorative Sustainable Materials, n.d).

Method

Preparation and characterisation of fillers

The pods of African mesquite were collected, cleaned, and pulverised into a fine powder, and then sieved to 100, 200, and 300 µm particle sizes. The samples were stored separately in clean, airtight containers to prevent moisture absorption before use. The filler samples were characterised using Gravimetric and Chemical method (Rabbani *et al.*, 2024) to obtain detailed information on their proximate and chemical composition. Bulk density

was determined in accordance with ASTM D7481-18, Method A. The mass (M) of a known volume (V) of a powder sample that had been passed through a sieve into a graduated cylinder was measured, and the bulk density was calculated using Equation 1.

$$D = \frac{M}{V} \dots \dots \dots \text{Equation 1}$$

Composite fabrication

The composites were fabricated using a hand mixing method according to the procedure reported by Jibril *et al.* (2025). After preparing the mold (cleaning, lining with foil paper, and applying a releasing agent), a pre-measured amount of the matrix (epoxy resin and hardener mixed in the ratio of 2:1 according to manufacturer’s instruction) and AMP filler (with 10 wt%, 20 wt%, 30 wt% and 40 wt% dosage) were mixed until uniformity was achieved through thorough and careful manual stirring. The mixture was then cast into the mold and spread evenly, followed by slight vibrations to eliminate trapped air and enhance particle-matrix bonding. The composite was allowed to cure at room temperature for 24 hours, enabling the crosslinking of the matrix. After curing, the composite was removed, trimmed, and properly labeled as AMP/ER composite (Plate II).



Plate II: Fabricated Composites

Flexural testing

The flexural test was conducted in accordance with ASTM D790-03 standard test method. The samples with a specimen of dimension 100 x 30 x 5 mm were conditioned at ambient temperature (27 °C and 68% RH) for 48 hours before mounting horizontally on the sample compartment of the universal material testing machine with a maximum load of 100 kN and a crosshead speed of 5 mm/min to assess the 3-point bending resistance. The test was carried out in triplicate (n = 3) to obtain and use average results, minimising errors. Flexural strengths and moduli were determined from the data obtained using Equations 2 and 3.

$$\sigma_f = \frac{3FL}{2bd^2} \dots \dots \dots \text{Equation 2}$$

$$\epsilon_f = \frac{FL^3}{4bd^3\Delta L} \dots\dots\dots \text{Equation 3}$$

Where σ_f is the flexural strength, F is the force (load) applied, L, b and d are the sample length, width and thickness respectively in mm, ϵ_f is the flexural modulus; ΔL is the deflection.

Impact testing

The impact strength of the composite samples was evaluated using the ASTM D6110 standard test on a V-notched sample measuring 100 × 11 × 5 mm, initially conditioned at ambient temperature (27°C and 68% RH) for 48 hours. The sample was fixed in the chamber of the Charpy impact tester, and a hammer with a 15 Joule energy capacity was released under gravity (9.8 ms⁻²) to strike the specimen at an angle of 90 ° to the face opposite the notch to break it. The work done in breaking the sample was recorded thrice (n=3), and the average of the results was used to improve measurement accuracy. The impact energy obtained is then divided by the cross-sectional area of the composite to determine the impact strength in kJ/m².

Thermal characterisation

The thermal property was studied in accordance with the ASTM E1131-08 standard test method using a Thermogravimetric Analyser (TGA). Approximately 18mg (preset to 100% by weight) of the clean and dry weighed sample was placed in an alumina crucible with a precision balance and the specimen holder is then allowed to cool to ambient temperature (15°C) before proceeding with the analysis at 10°C/min from the ambient temperature to a predetermined maximum temperature (950°C). During the analysis, the instrument recorded the weight loss as a function of temperature and time and finally generates a curve showing the mass changes due to dehydration and decomposition.

RESULTS AND DISCUSSION

The results of moisture content, basic proximate analysis, and bulk densities of the AMP filler are tabulated in Table 1.

Table 1: Properties of the African Mesquite Pods (AMP) Particles

PARAMETERS	AMP	BAMBOO (Mahanim <i>et al.</i> , 2011)
Ash content (%)	8.90	1.76
Moisture content (%)	6.80	15.30
Lignin (%)	23.70	13.71
Cellulose (%)	54.00	46.38
Hemicellulose (%)	13.40	31.46
Bulk Density (g/cm ³):		
100 µm	0.53	-
200 µm	0.51	-
300 µm	0.38	-

Flexural strength of AMP/ER composites

Flexural strength is the maximum bending stress that a material can withstand without failure. It is typically measured using (three-point or four-point) bending test (Dathan *et al.*, 2023). Three-point bending was applied in this study with the sample supported at two points and a load applied at the centre.

The effects of filler dosage and particle size on the flexural strength of the AMP/ER composites were examined, and the results are presented in Figure 2. The introduction of fillers into the pure matrix resulted in a significant decrease in the flexural strength of the unfilled epoxy matrix, which had a flexural strength of 52.67 MPa. The unfilled epoxy matrix sample (Control) has a uniform and extended molecular structure, allowing for a certain level of flexibility; however, the introduction of filler particles into the structure may disrupt the homogeneity of the load distribution, leading to a drop in their flexural strength (Chris-Okafor *et al.*, 2018).

Figure 2 shows higher flexural strength at low filler dosage (10 wt%), accounting for the overall peak flexural strengths of AMP/ER composites. This could be due to the improved stiffness and rigidity brought about by the even dispersion and distribution of fillers throughout the polymer matrix, which effectively prevents chain movement during deformation (Onyechi *et al.*, 2015). Subsequent dosing led to a progressive decline in flexural strengths, as also reported in some similar studies (Yusuf *et al.*, 2020; Kolawole *et al.*, 2019; Chris-Okafor *et al.*, 2018). This fall in strength can be attributed to agglomeration resulting from poor filler distribution as the dosage increases, which leads to a deterioration in its capacity to withstand bending stress. The high flexural strength (40.5 MPa) exhibited by 10 wt% AMP/ER composite appear to be 32% higher when compared to that of GF commercial composite material (made of HDPE and bamboo wood fibre) with 29.3 MPa flexural strength (Decorative Sustainable Materials, n.d.) flexural strength which could be attributed to the lower moisture content of AMP (6.80%) compared to that of bamboo with 15.30% moisture content (Mahanim *et al.*, 2011). Also, AMP/ER can be said to have comparatively higher stiffness than that of GF cladding due to its higher lignin content (Table 1) as since lignin is important in material rigidity and hydrophobicity (Zoghلامي & Paës, 2019).

The graph also portrays a decreasing trend in flexural strength with particle size, which aligns with the results of Kolawole *et al.* (2019), Lawal *et al.* (2019), and Seth *et al.* (2018). Kolawole *et al.* (2019) found that finer particles produced composites with higher flexural strength, attributing this to the larger surface area-to-volume ratio presented by smaller particles, which facilitates interaction with the resin and improves the process of stress transfer, ultimately increasing the flexural strength. On the other hand, larger particles not only lead to poor interfacial bonding between the particle and matrix but also generate void fractures at the composite’s interface, making the particles incapable of withstanding the stresses transferred from the matrix, thus weakening the flexural strength

(Seth *et al.*, 2018). Lawal *et al.* (2019) also found that larger particles resulted in a composite with lower flexural resistance. This was linked to the difficulty in achieving a homogeneous dispersion within the matrix as particle size increases, thus leading to the formation of gaps and weak areas that may degrade the composite’s mechanical integrity, such as flexural strength. A study by Mahmud *et al.* (2009) shows that the bulk density of the palm particles increases with a decrease in particle size, and finer particles tend to pack more closely together, reducing voids and

porosity and thus enhancing the mechanical strength of a structure (Akseli *et al.*, 2019).

Flexural modulus of the AMP/ER Composites

A composite's flexural modulus indicates the level of bending that a composite will experience under load. (Composite Envisions, 2023).

The effects of filler dosage and particle size on the flexural modulus of the AMP/ER composites is presented in Figure 3.

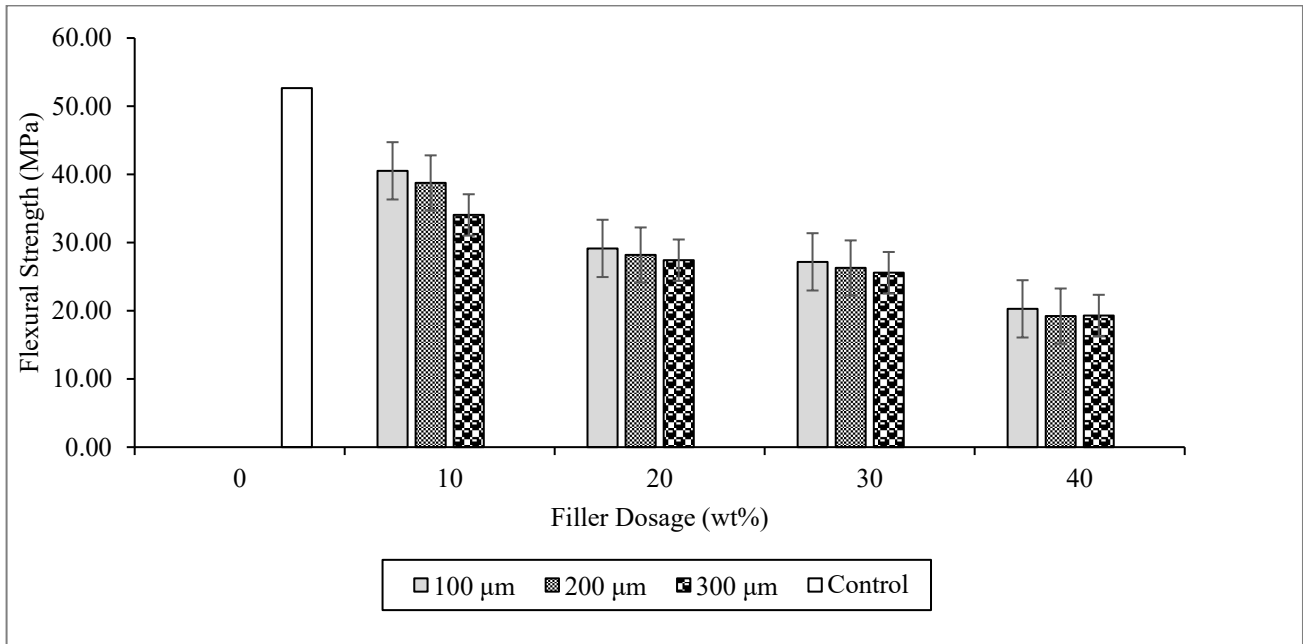


Figure 2: Effect of Filler Dosage and Particle Size on the Flexural Strength of AMP/ER Composite

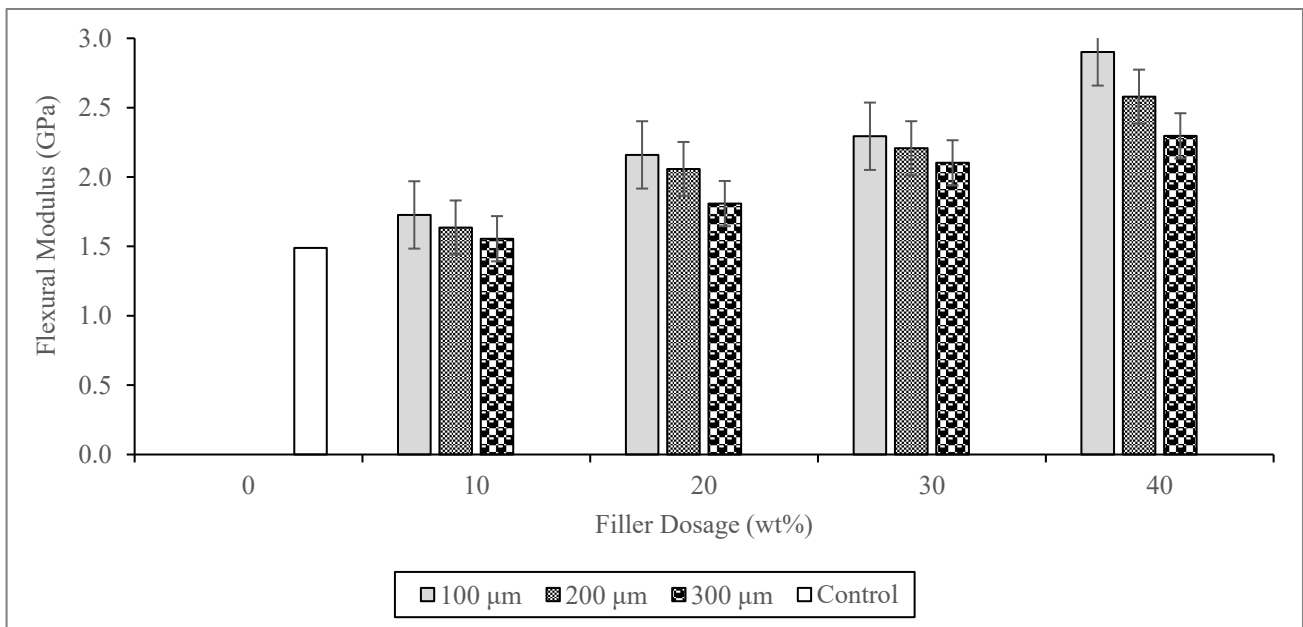


Figure 3: Effect of Filler Dosage and Particle Size on the Flexural Modulus of AMP/ER Composites

Figure 3 shows that the control sample exhibits a flexural modulus of 1.49 GPa, which increases upon the introduction of AMP fillers and as the dosage increases from 10 to 40 wt%. Similar trends were reported by several researchers (Basboga *et al.*, 2023; Kuan *et al.*, 2021; Kolawole *et al.*, 2019; Mengeloğlu & Shukur, 2018;

Rahman *et al.*, 2010). Rahman *et al.* (2010) attributed increases in flexural modulus to the enhancement in rigidity conferred to the soft matrix by the rigid lignocellulosic fillers. According to Ismail *et al.*, as cited in Basboga *et al.* (2023), one advantage that lignocellulosic fillers have over polymers is their comparatively higher

modulus. By the rule of mixture, this confers a higher modulus to the resulting wood plastic composite as the filler dosage increases (Mengeloğlu & Shukur, 2018). The effect of particle sizes on the flexural modulus of AMP/ER composites was also revealed in Figure 3. Even though the effect of particle size on flexural modulus was not as pronounced as that of filler dosage, a marginal drop

in flexural modulus was observed across all the sizes studied. This decline can be attributed to the composite's void content or fracture formation at the interface, the large particle's inability to withstand stresses transferred from the matrix, or the weak structure created by inadequate interfacial bonding between the large particle and matrix elements (Seth *et al.*, 2018).

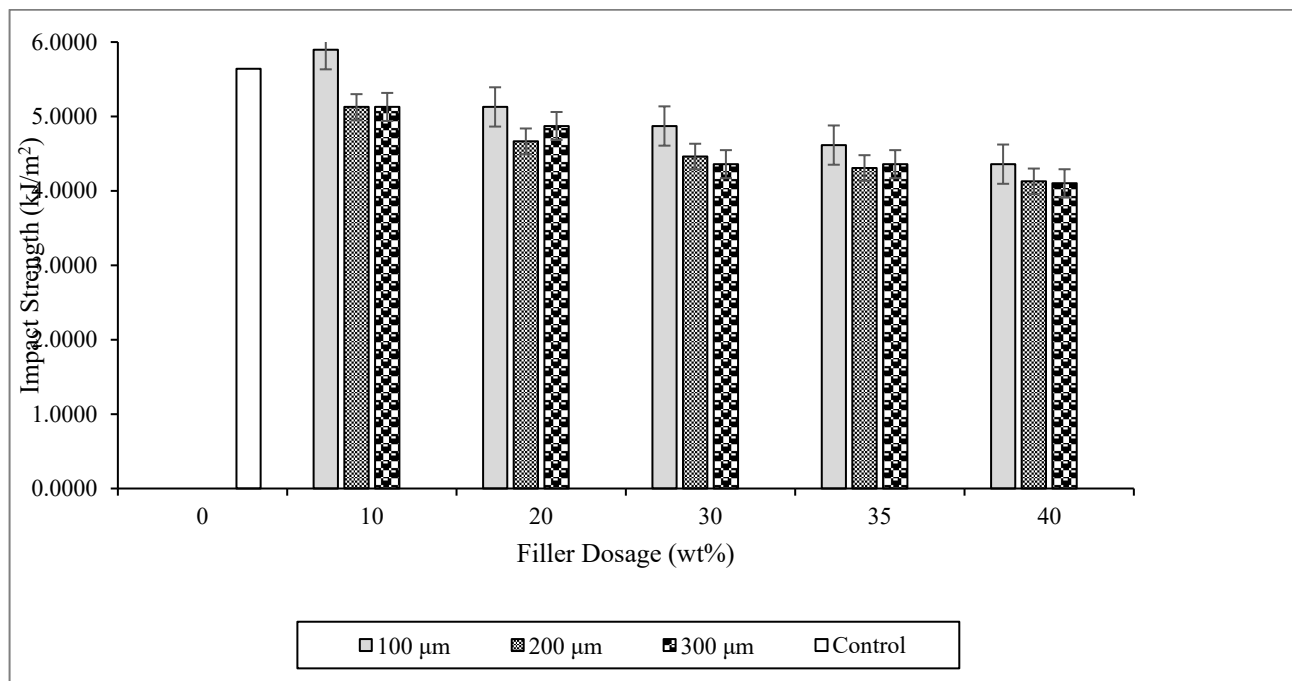


Figure 4: Effect of Filler Dosage and Particle Size on the Impact Strength of AMP/ER Composites

Impact strength of AMP/ER composites

The ability of a material to withstand abrupt and powerful impacts is measured by its impact strength, which indicates how much energy a polymeric substance can absorb before breaking (Kuan *et al.*, 2021).

The effects of filler dosage and particle size on the impact strength of the AMP/ER composites are presented in Figure 4.

Figure 4 illustrates a decreasing impact strength with an increase in filler dosage for both AMP/ER composites, regardless of particle size. The observed trend aligns with the findings of Kiziltas *et al.* (2016), Achukwu *et al.* (2015), and Sreekanth *et al.* (2009).

The control sample exhibited an impact strength of 5.64 kJ/m², but the introduction of fillers into the matrix boosted the impact strength of 100 µm AMP/ER as opposed to 200-300 µm AMP/ER composite, perhaps because finer particles can distribute more uniformly than coarser particles (Achukwu *et al.*, 2015). However, further increase in filler dosage beyond 10 wt% resulted in progressive decline in impact strength; thus, peak impact strengths (5.90, 5.13 and 5.13 kJ/m²) were obtained at 5 wt% while minimum impact strengths (4.36, 4.13 and 4.10 kJ/m²) were obtained at 40 wt% respectively with 100, 200 and 300 µm particle sizes. The composite with 10 wt% demonstrated a higher impact resistance (5.90 kJ/m²) than the commercial cladding, which has an impact strength of 4.86 kJ/m² (Decorative Sustainable Materials, n.d.). This could be due to the higher cellulose content in AMP fillers

compared to bamboo, as shown in Table 1. Bio-fillers containing higher cellulose content enhance mechanical bonding (Budiyantoro and Yudhanto, 2024).

One prominent factor that influences the overall impact strength of a composite is the elasticity of the constituent, which enhances the composite's impact strength if it is inherently elastic and deteriorates its impact strength if otherwise. Lignocellulosic fillers are reputed for their poor elasticity, which may impart brittleness to the composite. Thus, an increase in the concentration of such filler reduces the matrix's ability to absorb energy, thereby reducing toughness and resulting in a decrease in impact strength (Sreekanth *et al.*, 2009). Furthermore, Kiziltas *et al.* (2016) attributed the decrease in impact strength to the increasing filler dosage to poor filler distribution and hence agglomeration. Therefore, for applications requiring higher impact strength, it will be recommended to keep the AMP filler dosage as low as 10 wt%.

On the other hand, Figure 4 also reveals the effects of particle sizes on the impact strengths of the AMP/ER composite. The results depict a decreasing trend in impact strength with particle size. The decreasing impact strength with increasing particle sizes might be due to the strengthening mechanism that results from effective stress transfer between matrix and fillers, as finer fillers primarily undergo more effective dispersion within the matrix and strengthen the matrix-filler interfacial bonding, which in turn enhances the impact strength of the AMP/ER composite (Achukwu *et al.*, 2015). On the flip, larger

particles may create voids within the matrix, further compromising the impact integrity of the composites.

Thermal Stability of AMP/ER Composites

Thermogravimetric analysis (TGA) was employed to evaluate the thermal stability and decomposition behaviour of the Epoxy Resin (ER), AMP filler, as well as the AMP/ER composites. The TGA/DTG curves for these materials are presented in Figures 5 and 6.

The epoxy resin (ER) from Figure 5 showed improved thermal stability compared to the fillers. It displays an initial degradation temperature of 401°C, which represents

the temperature at which significant mass loss began. The maximum temperature (Tmax), observed at 456 °C, corresponds to the peak of the derivative thermogravimetric (DTG) curve and indicates the most intense stage of degradation. The lowest derivative weight loss rate of -2.4%/min further highlights the stepwise decomposition nature of the epoxy. The offset temperature was 830 °C, following which thermal degradation levelled off, indicating a high char residue of 41%, which suggests an energetic and thermally robust network structure, possibly due to extensive crosslinking.

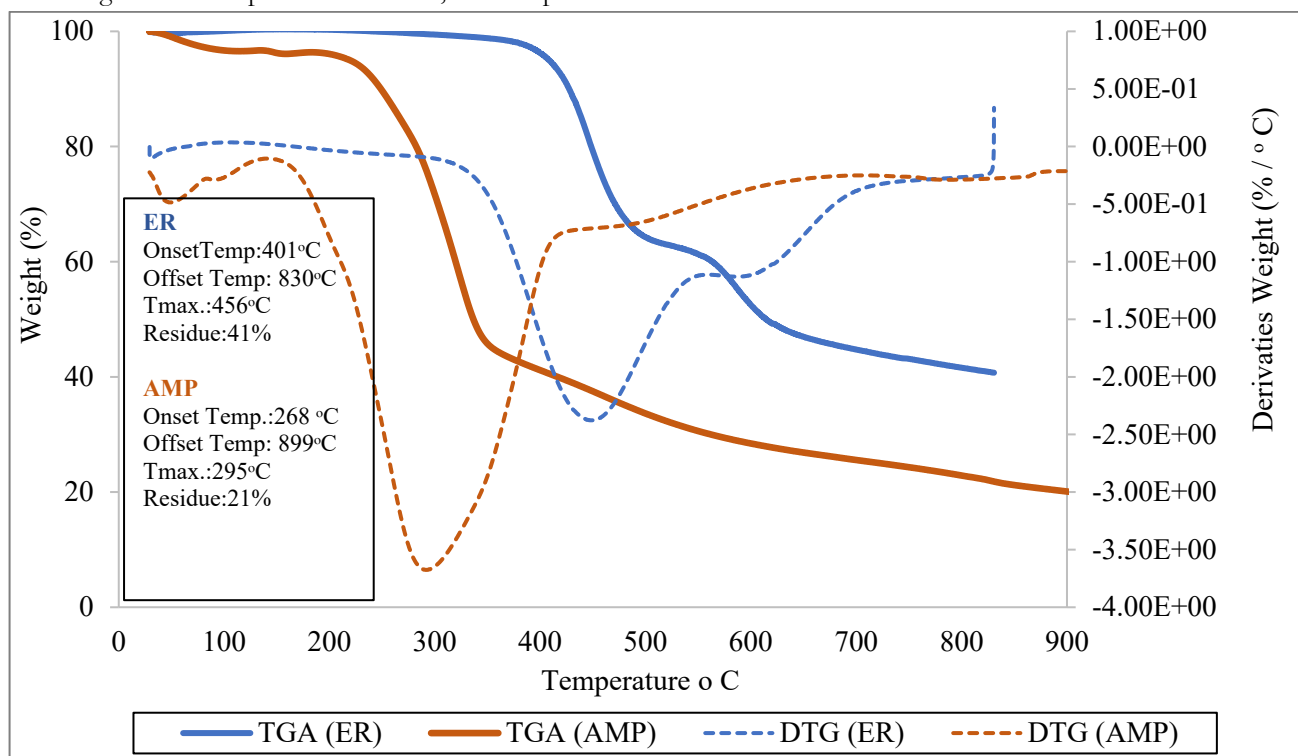


Figure 5: TGA/DTG Thermograms of the unfilled Epoxy Resin (ER) and AMP filler

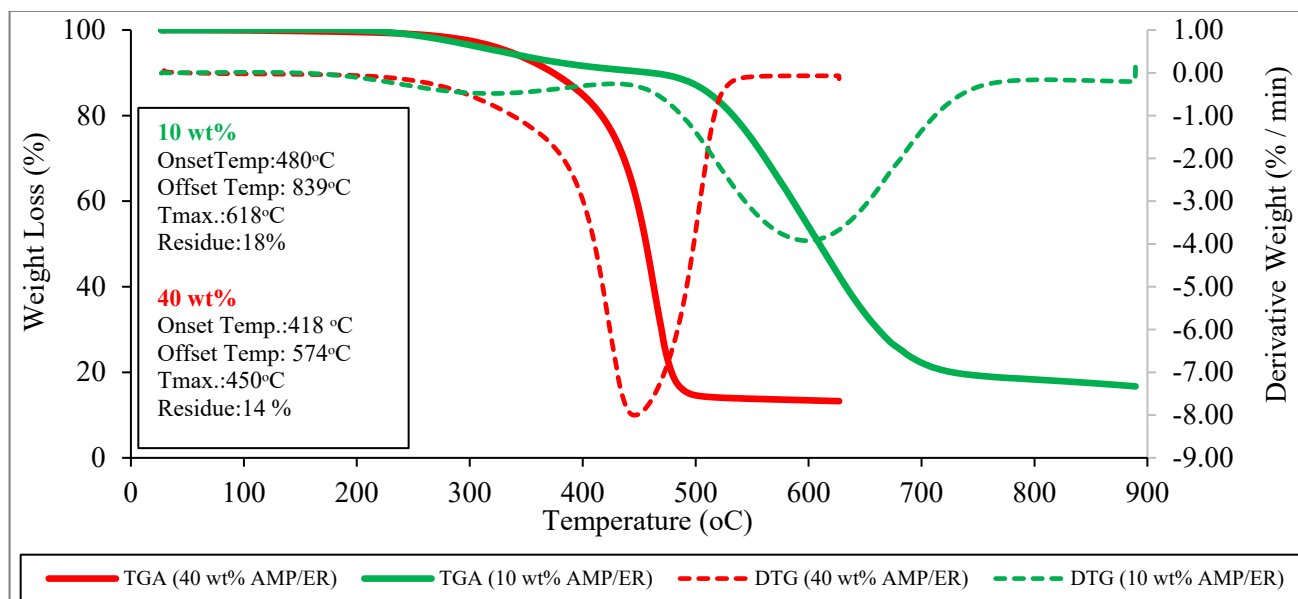


Figure 6: TGA/DTG Thermograms of AMP/ER Composites at 10 wt% and 40 wt% filler dosage

Conversely, the AMP filler was less thermally stable, as it had a lower onset temperature of 268 °C and a Tmax of 295 °C, indicating that thermal decomposition commenced earlier and peaked at a significantly lower

temperature. The DTG curve also showed that AMP had a greater rate of degradation (-3.67%/min) than the neat epoxy (-2.37%/min). Finally, the AMP filler also exhibited a lower char residue of 21 %, indicating that it

undergoes higher thermal degradation than the ER. The comparatively higher lignin and ash content value of AMP/ER composite over GF cladding signifies that AMP/ER would be more thermally stable than the GF cladding.

Figure 6 shows the TGA/DTG curves of AMP/ER composites containing 10 wt% and 40 wt% filler loading, respectively. At 10 wt% filler loading, the onset degradation temperature of AMP/ER composite is 480°C and leaves 18% residual weight after losing 82% weight. A further increase in the filler content to 40 wt% causes the onset degradation temperature to shift to 418°C, accompanied by a concomitant drop in residue to 14%, resulting in an 86% weight loss. Thus, from these results, it can be seen that the composite containing 40 wt% AMP loses weight faster compared to the 10 wt% AMP/ER composite, which signifies that the AMP/ER composite with a higher filler dosage has the lowest thermal stability. This pattern agrees with those established by Sozen *et al.* (2017). The heightened thermal stability observed at low filler loadings is attributed to the overriding effect of the thermally stable epoxy matrix, combined with enhanced interfacial adhesion and uniform particle dispersion at low filler contents, as explained by Nurazzi *et al.* (2021).

On the other hand, increased filler loadings can encourage particle agglomeration and other irregularities, which would render those areas susceptible to thermal degradation because of inadequate bonding with the epoxy matrix. Such a phenomenon raises the issue of the intrinsic low thermal stability of lignocellulosic fillers compared to the epoxy matrix, which consequently undermines the thermal stability of the composite (Yang *et al.*, 2005). These thermal degradation behaviours obtained corroborate the flexural strength properties of the composites. To start with, at 10 wt%, the AMP/ER composite exhibited enhanced flexural strengths of 40.53 MPa, compared to the lower strengths achieved at 40 wt% (20.28 MPa).

Derivative thermogravimetric (DTG) curves further reveal that the peak degradation temperatures (T_{max}) for AMP/ER composites occur at 618°C and 450°C for 10 wt% and 40 wt% filler loadings, respectively. The accelerated decomposition rate observed at higher filler content (40 wt%) is likely due to non-uniform particle distribution within the epoxy matrix, which facilitates premature chain scission. In contrast, at lower filler loadings, stronger cross-linking within the matrix delays chain scission and enhances thermal stability.

CONCLUSION

The conversion of waste pods from iron trees to commercially viable composites was achieved. Among the several properties that qualify a material for use in wall cladding, the International Organisation for Standardisation places more emphasis on water absorption, flexural, and impact strengths. The comparison of these properties of AMP/ER composite with GF commercial cladding fabricated from HDPE and bamboo wood composite revealed AMP/ER to be more

suitable for cladding application based on the flexural strength (40.5 MPa & 29.3 MPa respectively by the AMP/ER and GF) and impact strength (6.15 kJ/m² & 4.86 kJ/m² respectively by the AMP/ER and GF). The TGA also confirms that a lower filler dosage (5-10 wt%) yields a more favourable mechanical strength. With reference to the Flexural, Impact, and Thermal properties demonstrated by the AMP/ER, the composites can be said to be viable for interior wall cladding applications, especially in areas requiring high temperature resistance, when the filler dosage is kept between 5-10 wt% and the particle sizes are $\leq 100 \mu\text{m}$. However, it is highly recommended to assess its durability by conducting accelerated weathering tests.

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