Mechanical characteristics of stir-cast Irvingia wombolu reinforced Al-4wt% Cu composite

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Abstract: Irvingia wombolu shell particulates are not commonly used as reinforcing materials in aluminium composites, which makes this research novel and interesting. Investigating their potential as reinforcement can offer new insights into sustainable and cost-effective composite materials. In this experimental study, the microstructure, tensile strength, hardness, and impact energy of Irvingia wombolu reinforced Al-4wt% Cu composites were investigated. The Al-4wt% Cu composites containing 2, 5, 8, 11, and 14wt% IWSp were fabricated using the stir-casting technique. The microstructure of the developed composites was analyzed using optical microscope. The OM results revealed even dispersion of IWSp in the Al matrix, leading to increase in the ultimate tensile strength, hardness, and impact energy of the Al-4wt% Cu matrix, with maximum values of 152 MPa, 257 HV, and 58 J obtained at 8wt %, 14wt %, and 5wt % IWSp, respectively. Incorporation of IWSp above 8wt% led to a sudden decrease in ultimate tensile strength due to excess of hard IWSp in the Al matrix. The alloy matrix recorded a better percentage elongation value compared with the composite samples. The study concludes that IWSp has the potential to serve as an alternative reinforcing material for Al-4wt% Cu composites.

Keywords: Al-Cu; microstructure; impact energy; strength; Irvingia wombolu.

1. INTRODUCTION

Aluminium alloys are essential materials in modern industry, offering a unique combination of properties that make them valuable for a wide range of applications. Through alloying and reinforcement techniques, their mechanical properties can be tailored to meet specific requirements in various industries [1-8]. Metal matrix composites (MMCs) are a class of advanced materials that combine two or more distinct materials to create a material with enhanced properties. In MMCs, a metal matrix serves as the primary structural component, while a reinforcement phase, typically made of ceramics, carbon fibers, natural materials like green plant waste, or other high-strength materials, is dispersed within the matrix to improve the properties compared to the base metal. MMCs have better resistance to deformation under high temperatures and loads, making them suitable for applications where dimensional stability is crucial. The addition of ceramic reinforcements can significantly enhance thermal conductivity, hardness, tensile, impact energy, and compressive strength making them useful in heat exchangers and thermal management systems, wear-resistant components, aircraft and automobile components (engine parts, brake rotors, engine parts, and suspension components), armor and ballistic shielding components [2-15]. MMCs can be complex and costly, requiring specialized techniques such as powder metallurgy or infiltration methods, unlike traditional materials, which limit their widespread adoption in some industries [16-20].

The use of various eco-friendly green plant waste materials as reinforcing agents in aluminium (Al) alloy-based composites has been reported [21-31]. These materials include rice husk shell, groundnut shell, corn cob, eggshell, coconut shell, bamboo leaf, coconut fiber, periwinkle shell, horse eye bean seed shell, and African walnut kernel. However, there has been little report on the reinforcing characteristics of Irvingia wombolu shell in Al alloy-based composites. Irvingia wombolu, also known as African mango or wild mango, is a tropical fruit tree native to West Africa [32-37]. Its shell may have untapped potential as a reinforcing material for improving the properties of Al alloy-based composites. Hence, this research is aimed at exploring for the first time the mechanical characteristics of stir-cast Irvingia wombolu reinforced Al-4wt% Cu composite.
2. EXPERIMENTAL PROCEDURE

The Al-4wt%Cu alloy matrix was prepared using aluminum wire and copper rods with purities of 99.8% and 99.9%, respectively. The reinforcement; Irvingia wombolu shells was obtained from Uzo-uwani, Enugu State, Nigeria. The obtained shells were extracted, washed with distilled water, and sun-dried for 5 days. The dried shells were ground and sieved to a particle size of 65 µm. The Al-4wt%Cu alloy matrix was melted in a bailout crucible furnace and cast in a steel mold of dimension 250 x 16 mm². For each composite formulation, the temperature of the molten Al-4wt%Cu alloy matrix was reduced and the required weight percent (2%, 5%, 8%, 11%, or 14%) of Irvingia wombolu shell particulates (IWSp) was incorporated into the molten matrix. The mixture was stirred for 2 minutes to ensure uniform dispersion of IWSp. The molten composite mixture was then poured into a preheated mold and cooled inside the mold. Double-layer feeding stir casting technique was adopted in the preparation of the samples.

Tensile strength test was conducted on samples with dimensions: 50 mm gauge length, 8 mm gauge diameter, and 120 mm total length, using a 10kN capacity JPL tensile strength tester (Model:130812) in accordance to ASTM E8/E8M-21 (2018) standard. The hardness test was conducted using a Vickers hardness tester (Model: VM-50) at a load and dwell time of 183.9 kgf and 5 s, respectively. Three indentations were made on each sample surface and the diagonals of indentations were measured using a 20X Olympus BH optical microscope. The average diameter of the indentations was determined and the Vickers hardness values were calculated using an appropriate equation 1. The impact energy test was conducted on samples of dimensions 55 x 10 x 10 mm³ with notch depths of 2 mm according to ASTM D638 standards. Prior to the microstructural analysis, the cast samples were subjected to pretreatment steps: grinding, polishing, and etching in Keller's reagent. Optical microscopy (OM) was used for the microstructure analysis.

\[ HV = \frac{P}{d^2} \]  

(1) [38]

HV = Vickers hardness (HV), P = applied load (kgf), d = average diagonals of indentations (µm)

3. RESULTS AND DISCUSSION

3.1. Mechanical characteristics of Al-4wt%Cu and Al-4wt%Cu/IWSp composites

The percentage elongation, ultimate tensile strength, hardness, and impact energy of Al-4wt%Cu and Al-4wt%Cu/IWSp composites are presented in Figs. 1-4. The Al-4wt%Cu alloy matrix exhibited a percentage elongation of 38%. Incorporation of 2 wt% of IWSp led to a decrease in the percentage elongation of Al-4wt%Cu alloy matrix from 38 % 32 %. The percentage elongation showed a decreasing trend with increasing concentrations of IWSp. This behavior can be associated with increasing dispersion of IWSp in the Al matrix. (Fig. 5). The ultimate tensile strength and hardness of Al-4wt%Cu alloy matrix recorded about 4.7% and 3.7%, respectively after incorporation of 2wt%IWSp. The Al-4wt%Cu/IWSp composites recorded maximum ultimate tensile strength and hardness of 152 MPa and 257 HV at 8 wt% and 14 wt% IWSp additions. Further increase in the concentration of IWSp above 8 wt% led to a decrease in ultimate tensile strength of the Al-4wt%Cu/IWSp composites. This decline in properties can be linked to excessive dispersion of IWSp in the Al matrix. The impact energy of the Al-4wt%Cu alloy matrix increased from 46 J to 50 J after incorporating 2 wt% IWSp. The impact energy value increased further to 58 J after increasing the concentration of IWSp to 5 wt%, but recorded a decreasing trend after increasing the IWSp to 8 wt%.

3.2. Microstructure of Al-4wt%Cu and Al-4wt%Cu/IWSp composites

The microstructures of the developed Al-4wt%Cu and Al-4wt%Cu/IWSp composites are presented in Fig. 5. The OM image of the Al-4wt%Cu alloy matrix revealed the α-solid solution regions and secondary phases in the Al-matrix (Fig. 5a). The solid solution region indicates the solid solution of copper in aluminium. The secondary phase which is known to be Al₃Cu is presented as needle-like precipitate scarcely dispersed in the Al-matrix. The OM images of the Al-4wt%Cu/IWSp composites reveal particulates of IWSp in the Al-matrix (Fig. 5 b and Fig. 5c). This can be attributed to the improvement of the ultimate tensile strength and hardness of Al-4wt%Cu alloy matrix. The dispersion and quantity of these particulates are seen to increase in the Al-matrix with increasing concentrations of IWSp, leading to further increase in the hardness of Al-4wt%Cu/IWSp composite (Fig.4 and Fig. 5 c).
Fig. 1: Percentage elongation of Al-4wt%Cu/IWSp composite

Fig. 2: Ultimate tensile strength of Al-4wt%Cu/IWSp composite

Fig. 3: Hardness of Al-4wt%Cu/IWSp composite
4. CONCLUSION

The present research explored the mechanical characteristics of stir-cast Irvingia wombolu reinforced Al-4wt%Cu composite. The tensile strength, hardness, and impact energy of Al-4wt%Cu alloy matrix containing different concentrations of IWSp are investigated. Results of the study showed that the Al-4wt%Cu/IWSp composites demonstrated excellent mechanical characteristics. The incorporation of IWSp into the Al-4wt%Cu alloy matrix has varying effects on mechanical properties. While it generally increases ultimate tensile strength and hardness initially, there is an optimal concentration (8 wt% for ultimate tensile strength and 14 wt% for hardness) beyond which these properties decline due to excessive dispersion of IWSp. Impact energy also exhibits non-linear behavior with increasing IWSp content, with an initial increase followed by a decrease.

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