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Reinforcing potential of Irvingia wombolu shell particulates in Al-2Nb-0.5Si eco-composite

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Abstract: **The primary objective of this research is to investigate the potential of IWSp as reinforcement in Al-2Nb-0.5Si eco-composites. The study aims to assess various mechanical properties and microstructural characteristics to determine the effectiveness of IWSp as a reinforcing material. The Al-2Nb-0.5Si eco-composites were fabricated using the stir-casting technique. This process involves mixing the aluminum matrix with varying percentages of IWSp (1%, 3%, 5%, and 7% by weight) to create composite samples for testing. The microstructure of the developed composites was examined using an optical microscope (OM). The results indicate that the IWSp were evenly dispersed in the aluminium matrix. This even dispersion is crucial for enhancing the properties of the composites. The addition of IWSp led to an increase in the ultimate tensile strength of the Al-2Nb-0.5Si matrix, with a maximum value of 174 MPa achieved. The hardness of the composites also increased with the inclusion of IWSp, reaching a maximum value of 288 HV. The impact energy of the composites improved, reaching a maximum of 49.1 J. However, there was a sudden decrease in impact energy when IWSp was incorporated above 1wt%. The alloy matrix exhibited a better percentage elongation value compared to the composite samples, with a maximum value of 42%. The study concludes that IWSp has the potential to serve as an alternative reinforcing material for Al-2Nb-0.5Si eco-composites.**

Keywords: **Al-2Nb-0.5Si alloy; eco-composites; microstructure; strength; hardness.**

1. INTRODUCTION

Aluminium is inherently lightweight, making it ideal for applications where weight reduction is critical, such as aerospace, automotive, and transportation industries. This characteristic helps improve fuel efficiency and reduce overall energy consumption. Aluminium alloys are essential materials in modern industry due to their unique combination of properties, and their adaptability through alloying and reinforcement techniques ensures they can meet the specific demands of various applications across multiple sectors [1-8]. Metal matrix composites (MMCs) are indeed a fascinating class of advanced materials that offer a wide range of enhanced properties by combining two or more distinct materials. MMCs consist of a metal matrix as the primary structural component and a reinforcement phase, often made of ceramics, carbon fibers, natural materials, or other high-strength materials, dispersed within the matrix. This combination leads to several notable advantages and makes MMCs suitable for various applications [2-15]. MMCs are known for their excellent compressive strength, ensile strength, hardness, corrosion, and wear resistance, making them suitable for brake rotors, engine parts, suspension components, and armor and ballistic shielding components. MMCs can be tailored by adjusting the choice of matrix material, reinforcement type, and processing techniques. This flexibility allows engineers and materials scientists to design MMCs that meet the specific requirements of a wide range of industries and applications. MMCs have compelling advantages, but their specialized manufacturing techniques, material costs, and other challenges limit their widespread adoption in industries where cost-effectiveness, simplicity of manufacturing, or readily available materials are primary concerns [16-20].

The utilization of eco-friendly green plant waste materials as reinforcing agents in aluminum alloy-based composites represents a sustainable and environmentally responsible approach to material development. This approach can lead to improved material properties and reduced environmental impact, making it an attractive option for various industries seeking more sustainable materials solutions [21-37]. This present study is designed to explore for the first time the reinforcing potential of Irvingia wombolu shell particulate in Al-2Nb-0.5Si eco-composites.

2. EXPERIMENTAL PROCEDURE

The Al-2Nb-0.5Si 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-2Nb-0.5Si alloy matrix was melted in a bailout crucible furnace and cast in a steel mold of dimension 250 x 16 mm^2. For each composite formulation, the temperature of the molten Al-2Nb-0.5Si alloy matrix was reduced and the required weight percent (1%, 3%, 5%, and 7%) 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 ASTME8/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 mm^3 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.

$$HV = 1.8544 \cdot \frac{P}{d^2} \qquad (1)\ [38]$$

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

3. RESULTS AND DISCUSSION

3.1. Mechanical characteristics of **Al-2Nb-0.5Si/IWSp eco-composites**

The percentage elongation, ultimate tensile strength, hardness, and impact energy of Al-2Nb-0.5Si and Al-2Nb-0.5Si/IWSp composites are presented in Figs. 1-4. The Al-2Nb-0.5Si alloy matrix exhibited a percentage elongation of 42%. Incorporation of 1 wt% of IWSp led to a decrease in the percentage elongation of Al-2Nb-0.5Si alloy matrix from 42 % 37 %. 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-2Nb-0.5Si alloy matrix recorded about 19.05 % and 0.76 %, respectively after incorporation of 1wt%IWSp. The Al-2Nb-0.5Si/IWSp composites recorded maximum ultimate tensile strength and hardness of 174 MPa and 288 HV at 7 wt% IWSp additions. The impact energy of the Al-2Nb-0.5Si alloy matrix increased from 47 J to 49.1 J after incorporating 1 wt% IWSp. The impact energy value decreased after increasing the concentration of IWSp to 3 wt%. This behavior can be linked to the dispersion of IWSp in the Al-matrix (Fig. 5).

3.2: Microstructure of Al-2Nb-0.5Si/IWSp eco-composites

The microstructures of the developed Al-2Nb-0.5Si and Al-2Nb-0.5Si/IWSp eco-composites are presented in Fig. 5. The OM image of the Al-2Nb-0.5Si 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 niobium and silicon in the aluminium matrix. The secondary phase could be Al-silicide and/or Al_2Nb phases. The OM images of the Al- Al-2Nb-0.5Si/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-2Nb-0.5Si 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 ultimate tensile strength and hardness of Al-2Nb-0.5Si/IWSp eco-composite (Fig.4 and Fig. 5 c).

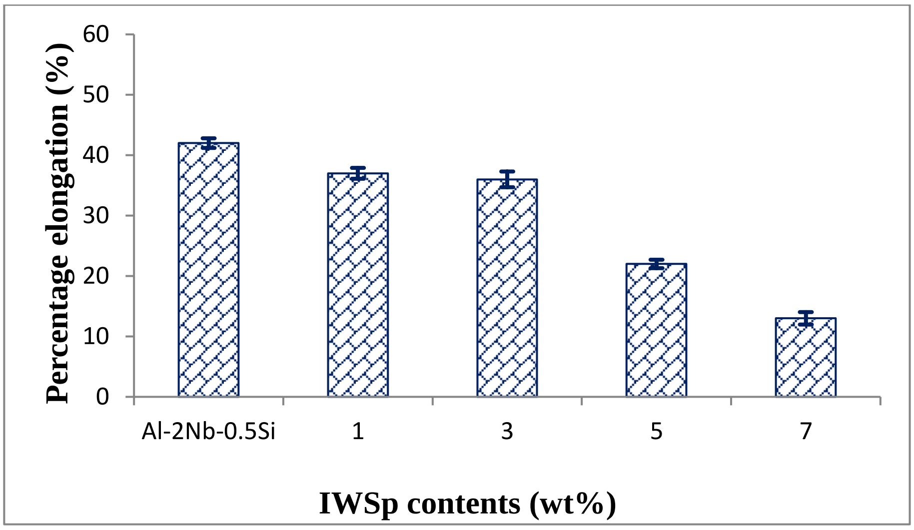

Fig. 1: Percentage elongation of Al-2Nb-0.5Si/IWSp eco-composite

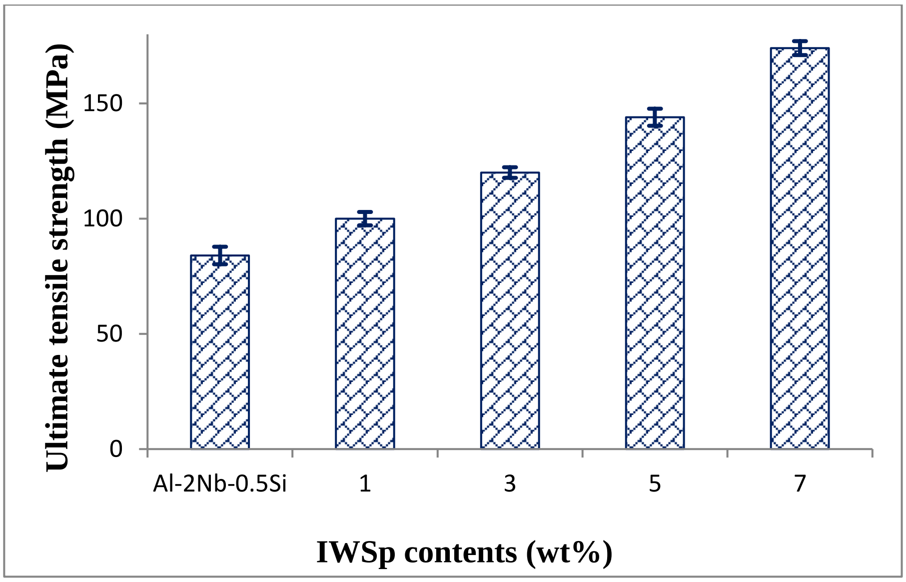

Fig. 2: Ultimate tensile strength of Al-2Nb-0.5Si/IWSp eco-composite

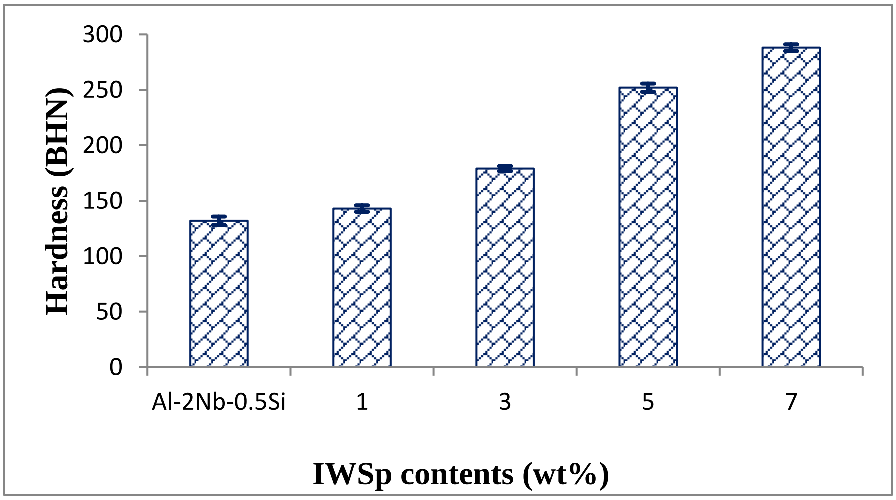

Fig. 3: Hardness of Al-2Nb-0.5Si/IWSp eco-composite

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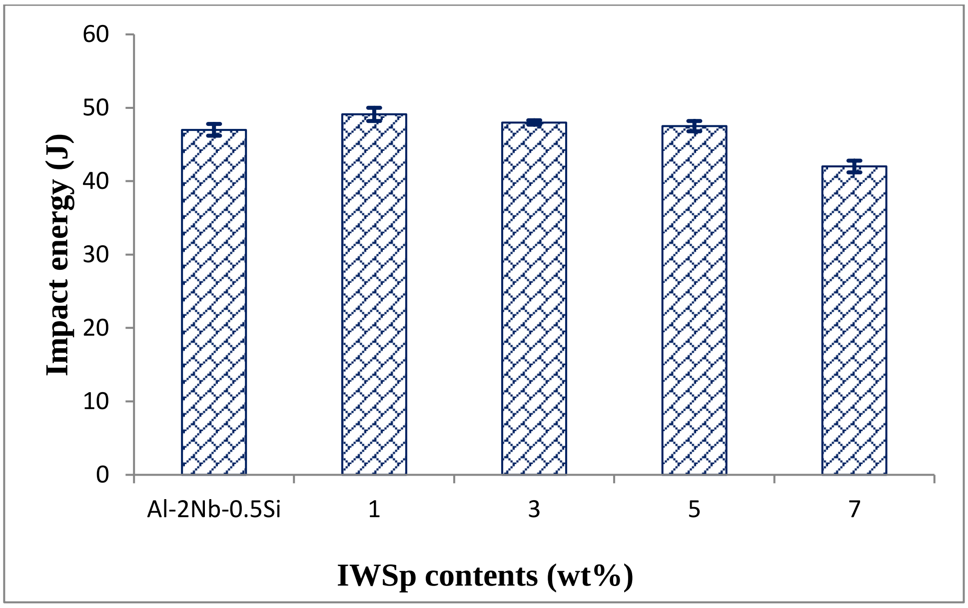

Fig. 4: Impact energy of Al-2Nb-0.5Si/IWSp eco-composite

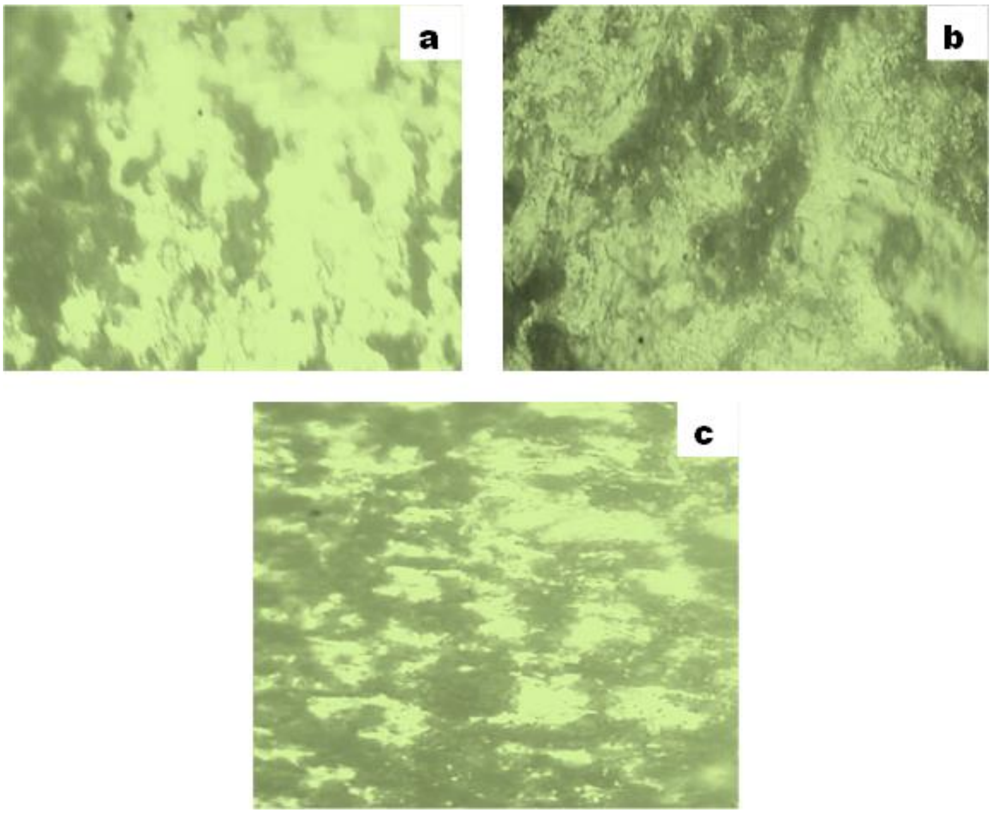

Fig. 5. Microstructure (OM) of (a) Al-2Nb-0.5Si (b) Al-2Nb-0.5Si-5wt%IWSp (c) Al-2Nb-0.5Si-7wt%IWSp

4. CONCLUSION

The reinforcing potential of Irvingia wombolu shell particulates in Al-2Nb-0.5Si eco-composite was examined in this present research. The effects of Irvingia wombolu sell particulates on the tensile strength, hardness, and impact energy of Al-2Nb-0.5Si alloy matrix were investigated. Results of the study showed that Irvingia wombolu shell particulates demonstrated excellent reinforcing potential in Al-2Nb-0.5Si/IWSp eco-composites. The incorporation of IWSp into the Al-2Nb-0.5Si alloy matrix increased ultimate tensile strength, hardness, and impact energy of the alloy matrix, recording

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maximum values of 174 MPa, 288 BHN, and 49.1 J. The improvements of mechanical properties are attributed to the presence and distribution of reinforcing particulates (IWSp) within the aluminium matrix, which enhanced the overall performance of the eco-composite material. The Al-2Nb-0.5Si alloy matrix exhibited better percentage elongation compared with the eco-composites. The impact energy decreased after incorporation of IWSp above 1wt%.

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