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NANOINDENTATION STUDIES ON EFFECTS OF RICE HUSK ASH-GRAPHITE-COPPER NANOPARTICLES ADMIXTURES ON MECHANICAL PROPERTIES OF Al 6063 HYBRID REINFORCED COMPOSITES

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ABSTRACT

Nanoindentation tests were used to evaluate the mechanical properties of Al6063 hybrid composites reinforced with rice husk ash, graphite and copper nanoparticles in the present study. Rice husk ash and graphite were mixed in fixed weight ratios of 3:1. Copper nanoparticles were varied from 1 to 4 weight ratio to prepare hybrid reinforced Al6063 based composites using two-step stir casting and spin casting technique, targeted for use in automobile industries. Nanoindentation tests were performed on the samples using indenter load of 100 mN, while the microstructures were characterized using optical microscopy. The hardness, reduced elastic modulus, elastic strain resistance and yield pressure of the hybrid composites increases with increase in copper nanoparticles content which can be attributed to good interfacial bonding and load transfer from aluminium matrix to the reinforcements.

Keywords: *composite, copper nanoparticles, rice husk ash, hardness, graphite, nanoindentation.*

INTRODUCTION

There is a global quest for materials that are cost-effective, while also possessing a high strength-to-weight ratio, continues to linger on. No conventional material entirely fits the bill. The search has, therefore, now long since moved from conventional materials to composites. Conventional materials do not possess the feasible combination of strength, stiffness, and density that the aerospace, automotive and marine industries [1], for instance, are looking for. Among the composites that have already been tested are the metal matrix composites (MMCs) in which ceramic particles or agro waste derivatives are added to conventional alloys.

Aluminum matrix composites (AMCs) remain an exciting class of metal matrix composites which is still stimulating interest among researchers because of its suitability for vast conventional and emerging technological and industrial applications. Some of the core areas where AMCs have successfully been used are aerospace industry, defense, automotive and marine industry [2 - 4]. Aluminium based alloys (AMMCs) are widely preferred, given their stiffness, strength, low weight, and density [5 - 7]. The AMMCs are reinforced with SiC, B_4C, zircon, Al_2O_3, and fly ash particles to enhance their mechanical and tribological properties considerably [8]. However, these properties still may not meet the requirements of the industries mentioned above. AMMCs are further reinforced with more than two other materials to produce aluminium hybrid metal matrix composites (AHMMCs) [9]. Hybrid composites are therefore better than the single reinforced composites [10, 11]. Several researchers have noted that reinforcements are not only more expensive but are also not readily available in most developing countries. It is, therefore, the need of the moment to develop cost effective composites using agro waste ash or industrial waste that is readily available and has lower densities. Since AHMMCs are attractive for use in various industries, therefore researchers in the area of composites are tasked with development of technically efficient AHMMCs to meet rising global demands. However, new production, processing routes and techniques are presently being developed for AHMMCs.

Table 1. Chemical Composition of Aluminum Alloy 6063.

Element	Si	Mg	Fe	Mn	Cr	Zn	Ti	Al
(%) composition	0.48	0.86	0.46	0.9	0.04	0.005	0.01	98.82

Cu nanoparticles currently attract significant research attention owing to their widespread application in powder metallurgical materials, casting and electronic circuits. Copper nanoparticles have also been considered [12, 13] as an alternative for noble metals in many applications, such as heat transfer and microelectronics [14, 15]. With recent advances in producing nanoparticles such as copper nanoparticles, it is expected that significant improvements can result from the incorporation of nanoparticles in metals to further enhance the properties. The wear behaviour of Al6063 alloy based reinforced with graphite-RHA-copper nanopaticles was investigated by Talabi et al. [16] and it was found that as the copper nanoparticles in aluminium hybrid reinforced composite increases so also the wear rate reduces, but there is dearth of information as to the effects of incorporation of copper nanoparticles on mechanical properties of Al6063 hybrid reinforced composites which has necessitated this research.

EXPERIMENTAL

The aluminium 6063 alloy was sourced from Tower Aluminium Ota in Ogun, Nigeria and its composition is presented in Table 1, while graphite was procured and copper nanoparticles (40 nm) were synthesized.

Production of Composites

The composites were produced via a two-step stir casting technique described by Talabi et al. [15] coupled with spin casting method. This involves carrying out charge calculation to determine the quantities of rice husk ash, graphite and copper nanoparticles needed to produce aluminium based composites. Weight ratios of mixed rice husk ash, graphite and copper nanoparticles reinforcing phase produced are shown in Table 2. Preheating of the RHA and graphite was done before adding to the melt to reduce dampness of the reinforcing materials and to improve wettability. Aluminium 6063 alloy was charged and heated in a gas fired crucible furnace to a temperature of 750°C above the liquidus. The liquid aluminium alloy was then allowed to cool down to a semi-solid state at about 600°C. At this stage, the preheated RHA, and graphite was introduced into the molten alloy with CuNP and stirred manually for 5 - 10 minutes. The composites slurry was later superheated to a temperature of about 850°C and a second stirring was carried out mechanically for 10 minutes to improve the distribution of the reinforcing particles in the matrix. The molten composites were later poured into a prepared sand mould using spin casting machine which was set at 700 rpm to produce as-cast Al6063 alloy based composites reinforced with RHA, graphite and CuNP. Fettling operations were carried out on the produced samples and samples machined for test.

Nanoindentation

The nanoindentation tests were performed with Anton Paar ultra-Nanoindenter (UNHT) fitted with a diamond Berkovich indenter. The indentation experiments were performed in accordance with ISO14577 [17], with the test run under constant load to reach possible maximum depth. The indentation experiments were performed using the user defined profile, using loads of 100 mN to make the indents at a loading rate of 10mN min^{-1} and held for 10 s. Six indentations were made per sample and their average serves as basis for analyses of the data generated. The user defined profile with the assistance of a built-in microscope which offers three sets of magnification, permits the selection and proper delineation of areas within the samples where the indents area to be made.

Table 2. Sample reinforcement weight ratio.

Composition
Al6063 alloy
Al6063/ 3RHA/1Gr
Al6063/ 3RHA/1Gr/1CuNP
Al6063/ 3RHA/1Gr/2CuNP
Al6063/ 3RHA/1Gr/3CuNP
Al6063/ 3RHA/1Gr/4CuNP

The hardness and elastic modulus of the samples were evaluated using Oliver-Pharr analysis [18]. Basically, the hardness (H) is defined as [19]

$$H = \frac{P_{max}}{A_c} \quad (1)$$

where P_{max} is the maximum load, and A_c is the projected area of the indentation.

The reduced elastic modulus (E_r), is considered as the elastic modulus which factors the elastic contributions of the specimen and the indenter tip, and is determined using the relation [20]:

$$\frac{1}{E_r} = \frac{1 - {v_s}^2}{E_s} = \frac{1 - {v_i}^2}{E_i} \quad (2)$$

where, E_i and E_s are the elastic modulus of the indenter and sample, respectively; while v_i and v_s are the Poisson's ratio of the indenter and the specimen, respectively. The hardness and reduced elastic modulus, the elastic strain to failure as the yield pressure were determined using

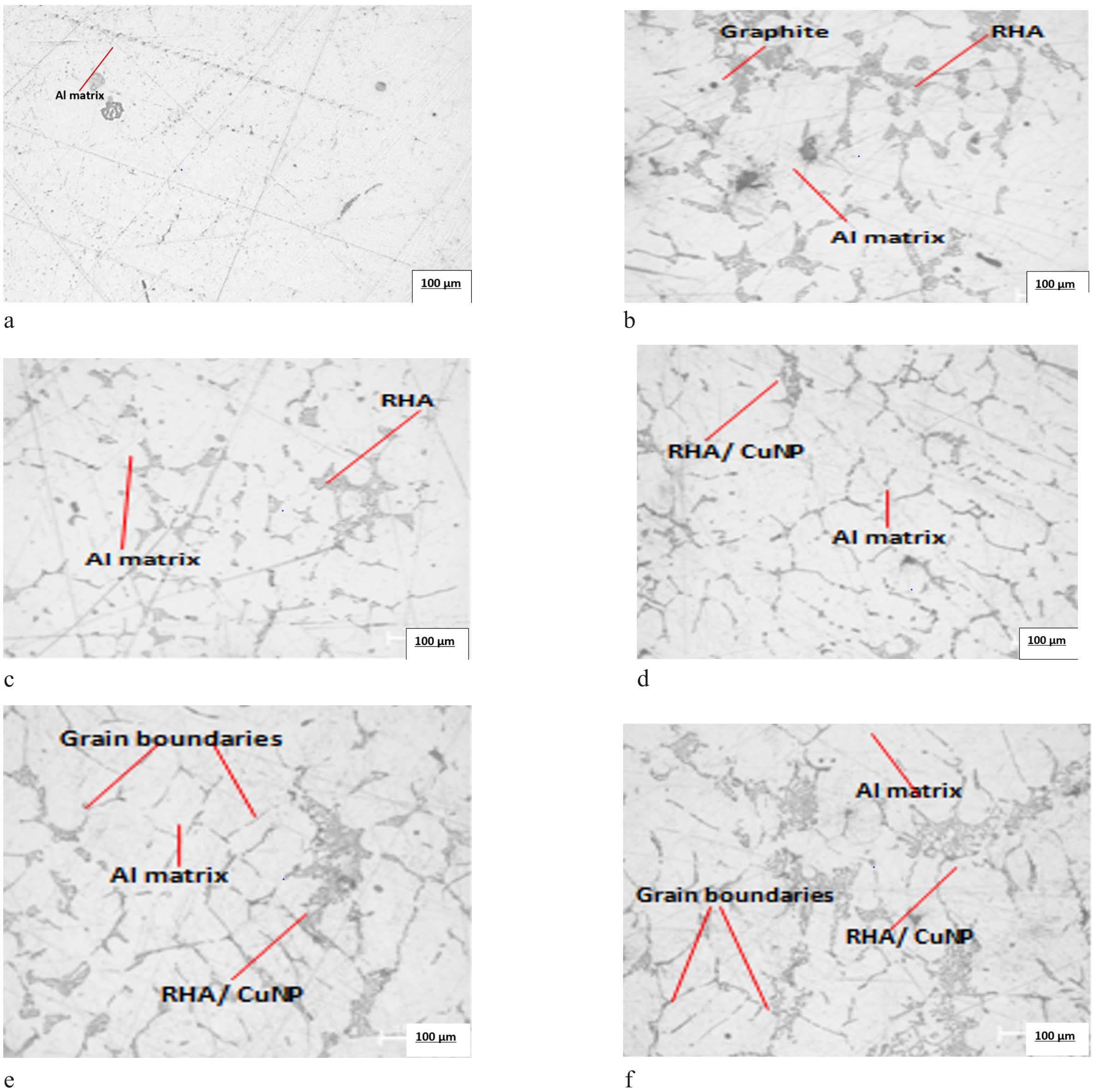

Fig. 1. a) Micrograph of unreinforced Al alloy - scale is difficult to see with this colour; b) Micrograph of Al/3RHA/1Gr composite; c) Micrograph of Al/3RHA/1Gr/1CuNP composite; d) Micrograph of Al/3RHA/1Gr/2CuNP composite; e) Micrograph of Al/3RHA/1Gr/3CuNP composite; f) Micrograph of Al/3RHA/1Gr/4CuNP composite.

the expressions [21]:

$$\text{Elastic strain to failure} = \frac{H}{E_r} \quad (3)$$

$$\text{Yield pressure} = \frac{H^3}{E_r^{\,2}} \quad (4)$$

Microstructural Characterization

The microstructure of the unreinforced and reinforced Al hybrid composites were presented in Fig. 1(a-e). There were good dispersions of RHA, graphite and copper nanoparticles in the Al6063 alloy matrix. With increase in copper nanoparticles concentration/fraction, the grain boundaries become visible. The microstructures revealed particle distribution patterns typical of double stir cast processed metal matrix composites which were considered to be of good quality [22].

Nanomechanical analysis

Load-displacement and depth-time curves of unreinforced and reinforced Al hybrid composites

The nanoindentation load-displacement curves for unreinforced and reinforced aluminium hybrid composites were subjected to indentation load of 100 Mn. It was observed in Fig. 2 that both the unreinforced and reinforced aluminium follows similar pattern for loading and unloading at indentation load of 100 mN. It was also observed that, unreinforced aluminium has the highest penetration depth of 3942.3 nm as compared to the reinforced aluminium composites under indenter loading of 100 mN, which shows that the indenter penetrate more into the unreinforced aluminium as compared to the reinforced aluminium. However, with the additions of reinforcements the penetration depth of the aluminium Al/3RHA/1Gr decreased and further addition of CuNP into the reinforcements, there was more decrease in penetration depth, with aluminium Al/3RHA/1Gr/4CuNP which had the least penetration depth at indenter loads of 100 mN. The penetration depth decrease as a result of increase in CuNP content was responsible for increase in hardness of the aluminium hybrid composites. As for the penetration depth versus time profile of unreinforced aluminium and aluminium hybrid composites reinforced with RHA, Gr and CuNP when subjected to indentation loads of 100 mN as shown Fig. 3, it was observed that after an initial rise, the penetration depth decreased with increasing time.

Hardness and reduced elastic modulus of unreinforced and reinforced Al hybrid composites

Fig. 4 shows the hardness and Fig. 5 shows the reduced elastic modulus for unreinforced and reinforced Al hybrid composites under the indenter load of 100 mN, it was observed that with addition of RHA and graphite to aluminum matrix, there was increase both in hardness and reduced elastic modulus. The hardness and reduced elastic modulus further increased with addition of CuNP to the hybrid composites, which is attributed to good interfacial bonding and strain field created around the reinforcements which impede motion of dislocations [5].

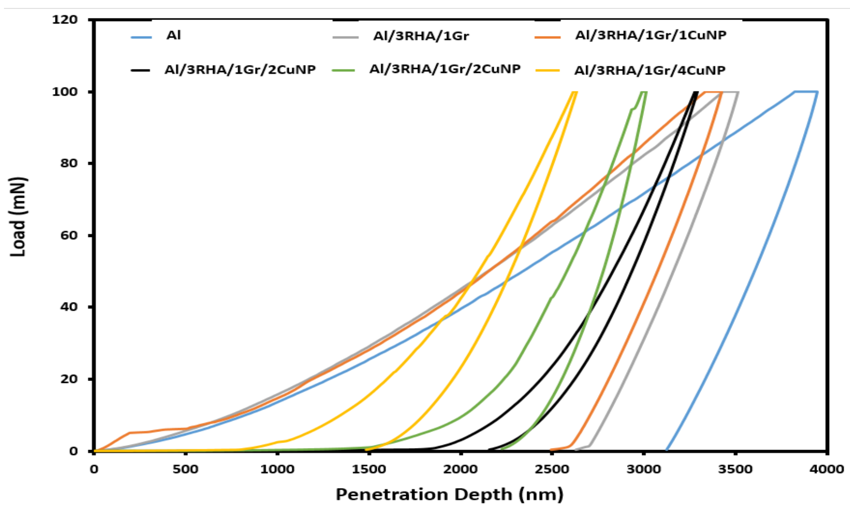

Fig. 2. The load at 100 mN.

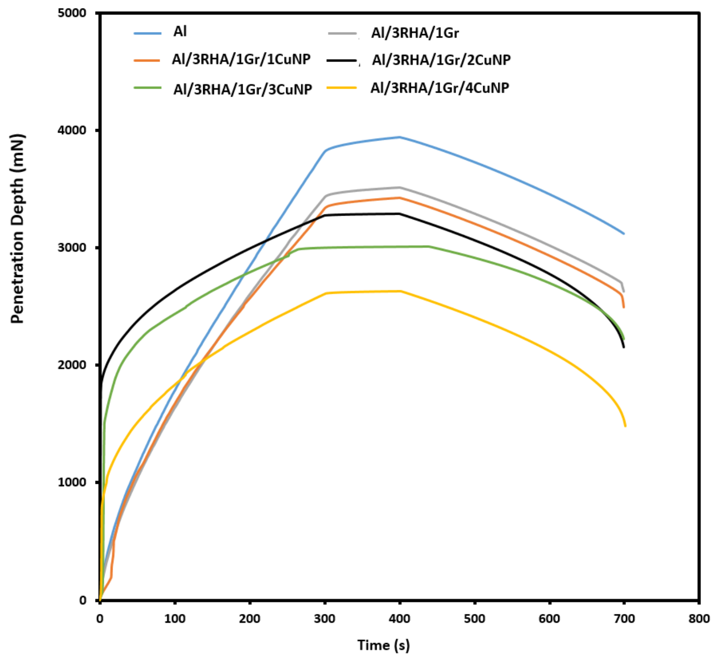

Fig. 3. Penetration depth with time at 100 mN.

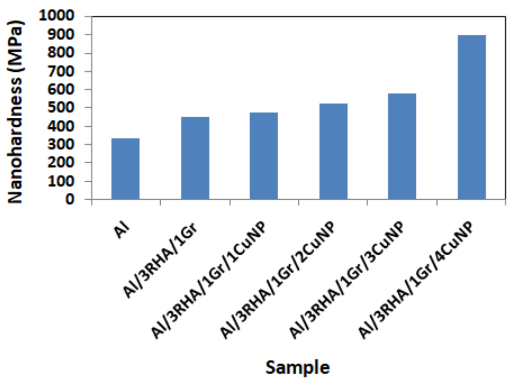

Fig. 4. Nanohardness of the unreinforced and reinforced Al hybrid composites at 100 mN.

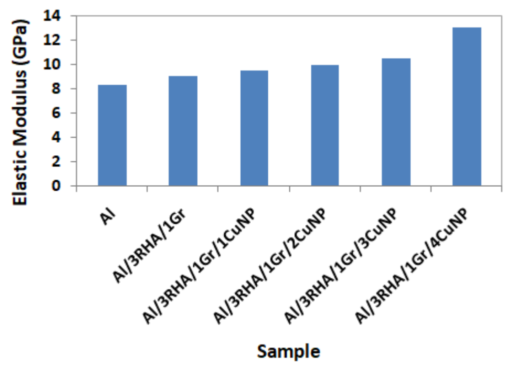

Fig. 5. Elastic modulus of the unreinforced and reinforced Al hybrid composites at 100 mN.

Elastic strain resistance and Yield pressure of unreinforced and reinforced Al hybrid composites

Fig. 6 shows the resistance to elastic strain to failure of the unreinforced and reinforced Al hybrid composites at 100mN. It was observed that the resistance to elastic strain to failure of the Al hybrid composites was improved with the addition of CuNP. The Al/3RHA/1Gr/4CuNP composite which contained 4 % CuNP had the highest resistance to elastic strain to failure, while the Al/3RHA/1Gr showed the least resistance out of the reinforced composites, which shows as the CuNP increases, so also the elastic strain to failure of the reinforced Al hybrid composites increases. Fig. 7 shows the yield pressure which serves as a measure to resistance to plastic deformation under load. It was observed the yield pressure of the Al hybrid composites was improved with addition of CuNP. The Al/3RHA/1Gr/4CuNP composite which contained 4 wt. % CuNP had the highest yield pressure. The significant importance of the improvement of the elastic strain to failure and yield pressure was an indication of good resistance to wear and impact loading of the Al hybrid reinforced composites.

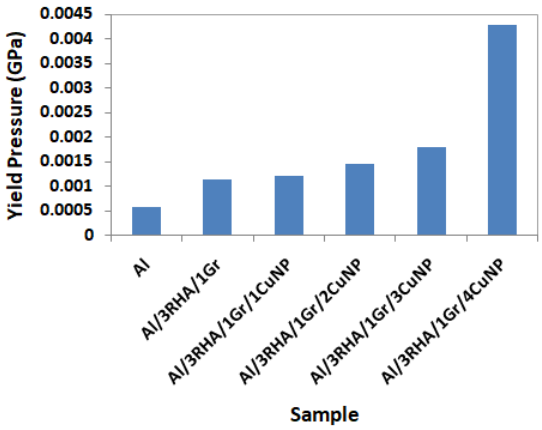

Fig. 6. Elastic strain resistance of the unreinforced and reinforced Al hybrid composites at 100 mN.

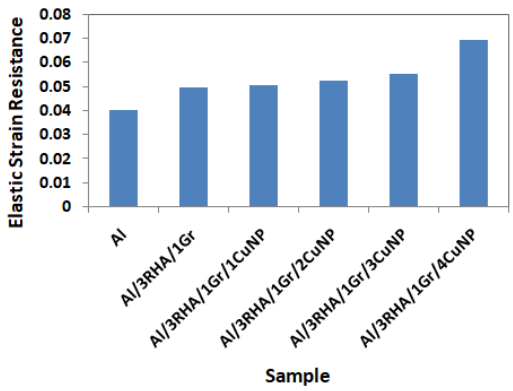

Fig. 7. Yield pressure of the unreinforced and reinforced Al hybrid composites at 100 mN.

CONCLUSIONS

In this study nanoindentation analysis was used to evaluate the mechanical properties of unreinforced and reinforced Al hybrid composites at 100mN. The hardness and reduced elastic modulus of the Al hybrid composites increases with increase in the CuNP content, which is attributed to good interfacial bonding and creation of strain field around the reinforcements which impede motion of dislocations. The elastic strain resistance and yield pressure were improved with increase in CuNP content.

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