CHARACTERIZATION OF MECHANICAL PROPERTIES OF ALUMINIUM BASED COMPOSITES REINFORCED WITH COPPER NANOPARTICLES

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ABSTRACT

The present study focuses on the investigation of physical and mechanical characteristics of Al6063 alloy reinforced with copper nanoparticles. The Al6063-Copper Nanoparticles Metal Matrix Composites were fabricated by following double stir casting method coupled with spin casting technique. The amount of reinforcement incorporation in matrix material was from 2 to 6 varied in interval of 2. Scanning electron microscopy, hardness measurement, tensile testing and impact toughness were used to characterize the composites produced. It was observed that as the density increases with the increase in addition of copper nanoparticles (CuNP), the porosity reduces. It was also observed that hardness increases with increase in copper nanoparticles addition. The ultimate tensile strength increases with increase in copper nanoparticles addition. The impact energy of reinforced composites improved with the addition of 2 wt. % of copper nanoparticles.

Keywords: copper nanoparticles, hardness, impact energy, reinforcement, porosity.

INTRODUCTION

Metal matrix composite (MMC) is a featured type of composite material composed of metal or alloys as the matrix phase, and the other component is embedded in this metal matrix and works typically as reinforcement. The main advantages of MMCs are the ability to dominate the physical and mechanical properties by a suitable choice of matrix and reinforcement volume fractions. Composites production is a low-cost process concerning their excellent performance [1 - 3]. Aluminium matrix composites (AMCs) are still deeply studied by researchers notwithstanding the already large corpus of literature available on the subject. Some of the core areas where AMCs have successfully been used are aerospace industry, defense industry, automotive industry, and marine industry [4 - 8]. AMCs are highly recommended because of the versatile property combinations, which they can be tailored to possess properties such as: high specific strength and stiffness, good corrosion and oxidation resistance, tribological properties, low coefficient of thermal expansion, among others [9 - 12].

Copper nanoparticles is one of the most active metals in modern industries due to possessing unique properties that make it a particularly precious and useful metal. It has unique thermal, electrical, and optical properties and is being consolidated into products that extend from chemical and biological sensors to photovoltaics [13]. Copper nanoparticles are frequently utilized in typical applications for antimicrobial coatings, wound dressings, keyboards, and biomedical devices presently copper nanoparticles have also been considered as an alternative for noble metals in many applications [14, 15], such as heat transfer and microelectronics [12, 16]. With new advances in producing nanoparticles such as copper nanoparticles, it is anticipated that considerable improvements can result from the incorporation of nanoparticles in composites to improve their mechanical properties. There is enormous potential for use of Al based MMC due to the greater properties and high degree of adaptability that they confers. It is seen that by using nano sized particulates as reinforcement, one can tailor and provide excellent properties to Al based composites compared to Al based alloy and micron sized individually reinforcement [17]. AMMC are fabricated to solve technological challenges for various applications including automotive components, aerospace parts and marine applications due to their performance, advantages and possibility to produce light weight components [18].

The wear behavior of Al6063 alloy based reinforced with graphite-RHA-copper nanoparticles was investigated by Talabi et al. 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 [19].

EXPERIMENTAL

Al6063 alloy with chemical composition as presented in Table 1 was used as the metal matrix for the investigation and the chemical composition of the aluminium alloy was determined using spark spectrometric analysis and copper nanoparticles (CuNP) having particle size of 40 nm selected for the research.

Composites Production

The composites were produced through a two-step stir casting technique together with spin casting method as described by Talabi et al. [12, 20]. The quantities of copper nanoparticles needed to produce aluminium based composites were determined by carrying out charge calculation. Table 2 shows copper nanoparticles reinforcing phase weight ratio. The charged aluminium 6063 was heated at a temperature of 750°C above the liquidus in a gas fired crucible furnace. The liquid aluminium alloy was allowed to cool down to a semi-solid state at about 600°C. At this period, the preheated CuNP was introduced into the molten alloy; reason for this was to improve wettability and stirred manually for 5 - 10 minutes. The composites slurry was afterwards superheated to a temperature of about 850°C and another stirring was carried out mechanically for 10 minutes to further advance the distribution of the reinforcing particles in the matrix. The molten composites were later poured into a sand mould prepared using spin casting machine which was set at 700 rpm to produce as-cast Al6063 alloy based composites reinforced with CuNP. Fettling operations were carried out on the samples produced and samples were machined for test.

Density Measurement

Density measurements were carried out to study the effect of varied CuNP weight proportions on the densities of the composites produced. The measured experimental density was also used to estimate the porosity levels in the composites. This was done by comparing the experimental and theoretical densities of the CuNP reinforced composite produced [21]. The experimental density for each composite was evaluated by weighing the test sample using a high precision electronic weighing balance with a tolerance of 0.1 mg. The measured weight in each case was divided by the volume of the respective sample. The theoretical density was evaluated using the rule of mixtures given in equation 1:

$$\rho_{Al6063/CuNP} = Wt_{Al6063} \times \rho_{Al6063} + Wt_{CuNP} \times \rho_{CuNP} \quad (1)$$

Table 1. Chemical Composition of Al 6063 Matrix Alloy (wt. %).

Element	Al	Si	Fe	Cu	Mn	Mg	Ni	Zn	V
Composition, %	98.76	0.47	0.23	0.22	0.012	0.39	0.001	0.01	0.01

Table 2. Composite Density and Estimated Percent Porosity.

Sample Designation	Composition Al6063: CuNP	Theoretical Density	Experimental Density	Porosity, %
AA	100:0	2.70	2.65	1.85
AA2CNP	98:2	2.82	2.77	1.64
AA4CNP	96:4	2.94	2.90	1.21
AA6CNP	94:6	3.08	3.05	0.94

where: $\rho_{Al6063/CuNP}$ is the composite density; Wt_{Al6063} isthe weight fraction of Al6063 alloy; ρ_{Al6063} is the density of Al6063 allo; Wt_{CuNP} is the weight fraction of CuNP; ρ_{CuNP} is the density of CuNP.

The percent porosity of the composites was determined from the respective experimental and theoretical densities using the relation in equation 2:

$$\% \text{ Porosity} = \frac{\rho_{TE} - \rho_{EX}}{\rho_{TE}} \text{ X } 100\% \quad (2)$$

where ρ_{TE} is theoretical density (g cm^{-3}) and ρ_{EX} is experimental density (g cm^{-3}).

Scanning Electron Microscopy

The metallographic characterization of the prepared composite samples was done using scanning electron microscopy (SEM) (Make: JEOL; JSM-6510LV; Japan).

Hardness Test

The hardness test in accordance with the specification of ASTM E-384 standard [22] was conducted on the prepared composite samples. The hardness of the composites was measured by applying a direct load of 120 kgf for 10 seconds on flat smoothly polished plane parallel specimens of the composites. Multiple hardness tests of five measurements were performed on each sample and the average value was taken as a measure of the hardness of the specimen within the tolerance of ± 2 %.

Tensile Test

Tensile tests were performed on the composites produced following standard procedures in accordance with ASTM E8M15a standard [23]. The samples for the test were machined to dimensions of 6 mm diameter and 30 mm gauge length. The test was performed at room temperature using an Instron universal testing machine which was operated at 10^{-3} s^{-1} strain rate. The tensile properties evaluated from the tensile test were ultimate tensile strength and specific strength.

Impact Test

The impact energy of the specimens were evaluated using (Hounsfield Balance) Impact Testing Machine, the specimens for each of the hybrid composites were machined to dimensions of 8 mm diameter and 18 mm length. The specimens were notched 2 mm in (V shape), the value of the energies absorbed in fracturing the test - piece were measured in joule and the average readings were calculated and recorded as the impact strength. This was done in accordance with ISO 148-1-2016 [24].

RESULTS AND DISCUSSION

Composite densities and percent porosities

The composite densities and percent porosities are presented in Table 2. It was observed that the composite densities increased with increase in wt. % of copper particles. The Al-based composite composition containing 6 wt. % copper particles had a density of 3.08 g cm^{-3}, which was 9.2 % higher than the composite containing 2 wt. % Copper nanoparticles (2.82 g cm^{-3}). The percentage porosities of all the developed composites were less than 1.65 %, and noted to be less than 4 %, which was reported to be the maximum permissible in cast metal matrix composites [20]. This pointed to the reliability and efficiency of the double stir casting process and spin casting technique, which was reported to break the surface tension between the Al alloy melt and the particulates, and allows for entrapped air bubbles aspirated into the slurry to escape during processing [21, 25].

Fig. 1(a) shows SEM image for the as-cast Al 6063 alloy without the addition of copper nanoparticles (CuNP) and Fig. 1 (b-d) shows SEM images for 2, 4 and 6 volume percent CuNP reinforced Al 6063 alloy composites. It was observed that CuNP particulates were visible and a good dispersion of the particulates in the Al 6063 alloy matrix was obvious as the CuNP increases. This could be a pointer to the efficiency of double stir casting and spin casting technique.

Mechanical Properties

Hardness

The hardness values of the composites produced were presented in Fig. 2. It was observed that the hardness values of the composites reinforced with copper nanoparticles, increased with increase in wt. % copper particles as compared to the unreinforced alloy. This amounts to approximately 21 % increase in hardness when 6 wt. % copper particles were added to the Al 6063 alloy. The observed increase in hardness may be due to higher volume fraction of copper particles. As the

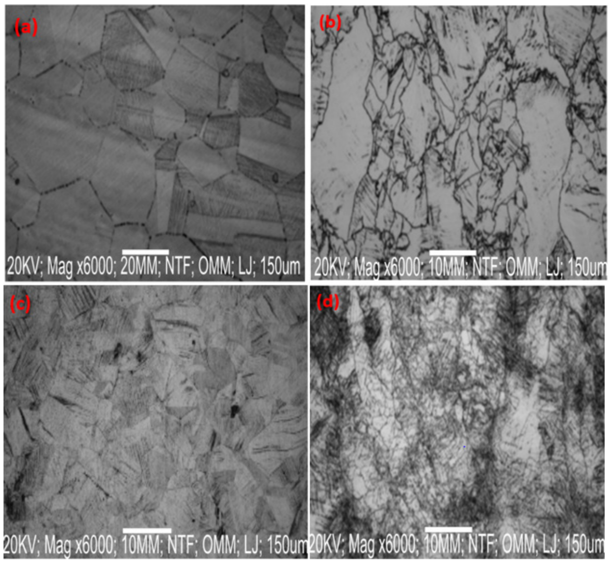

Fig. 1. SEM micrographs of the: (a) unreinforced Al 6063 alloy; (b) AA2CNP developed composite; (c) AA4CNP developed composite; (d) AA6CNP developed composite.

copper nanoparticles increases from 2 wt. % to 6 wt. %, the hardness values increase [26]. This can be attributed to low porosity obtained as the copper nanoparticles concentration increases and strain fields created around the particulates which impede the motion of dislocation, thereby causing increase in hardness values [25]. The contribution of copper particulates was supported by the investigation of Reddy et al., who investigated the addition of copper particulates to the Al- 5wt % Cu alloy, the resultant composite hardness increased to 532 MPa, with an increase of 44 % [27]. This was also supported by Talabi et al. who investigated nanoindentation studies on effects of rice husk ash-graphite-copper nanoparticles admixtures on mechanical properties of al 6063 hybrid reinforced composites, with addition and increase in copper nanoparticles the nanohardness increases [28].

Impact energy

The impact energy values of the composites produced were presented in Fig. 3. From the results obtained, the ability of the composites to absorb energy was improved with the reinforcement. It was observed that the impact energy of the composites containing copper nanoparticles have values higher than the unreinforced Al 6063 alloy. The improved impact energy, was attributed to the presence of the copper nanoparticles

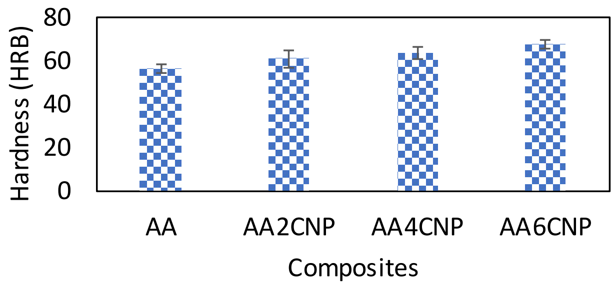

Fig. 2. Hardness values of the unreinforced Al 6063 alloy and Al 6063 alloy based composites.

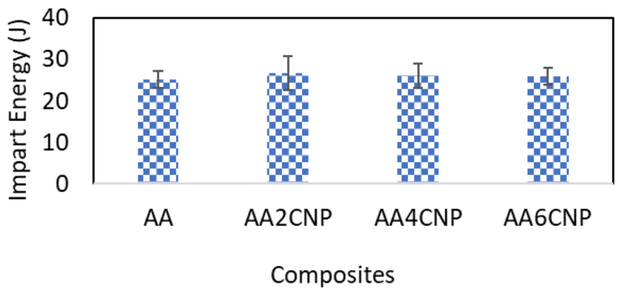

Fig. 3. Impact energy values of the unreinforced Al 6063 alloy and Al 6063 alloy based composites.

which was similarly a ductile material as Al but stronger. Ductile materials were known to generally show a better resistance to crack propagation because of the tendency to redistribute applied stresses and strains by plastic deformation, which can also facilitate crack tip blunting-deflating the effect of stress concentration [29]. Hence, the inherent ductility of the copper nanoparticles, contributes to the intrinsic toughening of the aluminium base composite. However, impact energy decreased a little when the copper nanoparticles were increased from 2 wt. % to 4 wt. % and 4 wt. % to 6 wt. %, respectively.

Ultimate tensile strength

The ultimate tensile strength (UTS) values of the unreinforced Al 6063 alloy and reinforced composites were presented in Fig. 4. The result shows that the UTS values of the composites were higher than the unreinforced Al 6063 alloy. It was observed that the ultimate tensile strength values did vary in a consistent manner and it was also observed that the UTS values of the copper nanoparticles reinforced composites increased as the weight percent of the reinforcement

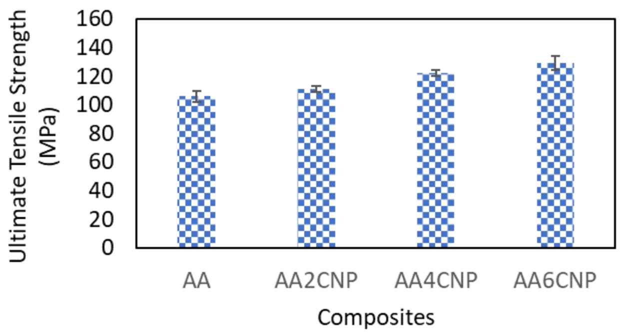

Fig. 4. Ultimate tensile strength values of the unreinforced Al 6063 alloy and Al 6063 alloy based composites.

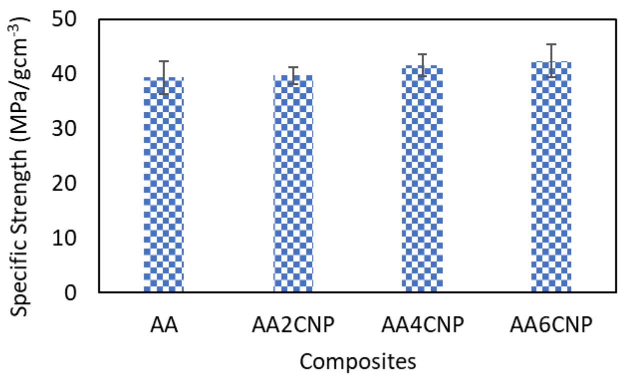

Fig. 5. Specific strength values of the unreinforced Al 6063 alloy and Al 6063 alloy based composites.

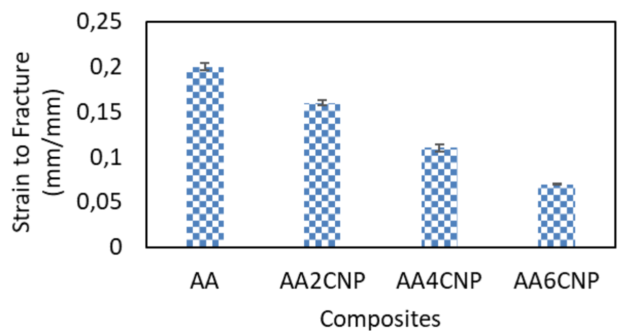

Fig. 6. Strain to fracture values of the unreinforced Al 6063 alloy and Al 6063 alloy based composites.

in the matrix increased. The percent increments in UTS of the copper nanoparticles reinforced Al 6063 based composite were 4.7 %, 15.1 % and 21.7 %. The strength of the composites increased as the presence of reinforcement particles increased due to the mechanisms of direct and indirect strengthening. The improvement and increase in tensile strength which was attributed to direct strengthening occurs in the composites with the transfer and distribution of load from the softer matrix to the harder and stiffer particles through the interface between matrix and reinforcements [30, 31]. The increase in dislocation density from the indirect strengthening mechanism results on account of thermal mismatch since the solidifying metallic matrix and the refractory particles have different coefficient of thermal expansion [30].

Specific strength

The specific strength values of the developed composites were presented in Fig. 5. It was observed that the specific strength of the composites were higher than the unreinforced Al 6063 alloy and as the wt. % of copper nanoparticles increases, the specific strength of the composites increases, even with increase in the density of the developed composites as presented in Table 2. The composite AA6CNP had the highest specific strength of 42.32 MPa g^{-1} cm^3 as compared to other hybrid reinforced composites.

Strain to fracture

The strain to fracture values of the unreinforced Al 6063 alloy and the developed composites were presented in Fig. 6. The strains to fracture of the composites were observed to be highest for the 2 wt. % copper nanoparticles reinforced composite and reduce with further increase in the weight percent of the copper nanoparticles. This was an indication that the 2 wt. % copper nanoparticles addition improves the composite capacity to tolerate more plastic strain before fracture in comparison with the other composite compositions produced.

CONCLUSIONS

There is a great future for these composites due to their superior performance. These composites are expected to have substantial applications in automobiles, aerospace and marines. The mechanical behaviour of Al6063 alloy matrix composites containing copper nanoparticles (CuNP) as reinforcements has been investigated. These results show that the addition of copper nanoparticles to Al6063 alloy reduced the porosity and increased the density of the composites. Increase in copper nanoparticles content led to a significant increase in hardness of the composites due to strain fields created around the particulates which impede the motion of dislocation, thereby causing increase in hardness.

A good uniform distribution of the copper nanoparticles in the matrix of the Al6063 alloy was also produced. The tensile properties and impact energy of the composites improved with the addition of copper nanoparticles.

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