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Original article

# Mechanical Behaviour of Aluminium Hybrid Composites Reinforced with: Rice Husk Ash - Silicon Carbide - Copper Nanoparticles

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## ABSTRACT

*The mechanical behaviour of Al6063 alloy matrix composites reinforced with rice husk ash (RHA), silicon carbide (SiC) and copper nanoparticles (CuNP) has been investigated. Rice husk ash and silicon carbide mixed in fixed weight ratios of 3: 1 while 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. Hardness measurement, tensile testing, impact toughness, optical and scanning electron microscopy were used to characterize the composites produced. It was observed that as the density increases with the increase in addition of copper nanoparticles, the porosity reduces. It was also observed that hardness increases with increase in copper nanoparticles addition. The ultimate tensile strength and impact toughness increased with increase in copper nanoparticles. The impact toughness of reinforced composites improved with increase in copper nanoparticles addition. The composition with 4 wt. % copper nanoparticles exhibited superior combination of properties that may be useful for design of components for automobile application.*

Key words: *aluminium matrix composite; rice husk ash; silicon carbide; copper nanoparticles*

## 1. INTRODUCTION

Aluminum matrix composites (AMCs) remain an interesting class of metal matrix composites which still stimulate interest among researchers because of its suitability for vast conventional and emerging technological applications. There is a growing interest in exploring developmental options for low-cost aluminium matrix composites (AMCs) with the hope of still maintaining their high performance levels in service applications [1]. Aluminium based alloys (AMMCs) are widely preferred, given their stiffness, strength, low weight, and density [2–4]. The AMMCs are reinforced with SiC, $B_4C$, zircon, $Al_2O_3$, and fly ash particles to enhance their mechanical and tribological properties considerably [5]. Some of the core areas where AMCs have successfully been used are aerospace industry, defense industry, automotive industry, and marine industry [6 - 8]. 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]. However, research in developing countries have taken a new turn embarking on research which use agricultural wastes and industrial by-product derivatives as constituents of the reinforcements in AMCs [8]. Lots of studies published in the area of use of alternative derivatives from agricultural and industrial by-products have emphasized the advantages of the derivatives over traditional ceramic reinforcement

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materials [12, 13]. Copper 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 as an alternative for noble metals in many applications [14, 15], such as heat transfer and microelectronics [16, 17]. With recent advances in producing nanoparticles it is expected that significant improvements can result from the incorporation of nanoparticles in composites to further enhance their properties [18]. The wear behaviour of Al6063 alloy based reinforced with graphite-RHA-copper nanoparticles is investigated by Talabi *et al*., 2020 [18] and it is 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.

## 2. MATERIALS AND METHOD

### 2.1 Materials

Al6063 alloy which was sourced from Tower Aluminium Ota in Ogun, Nigeria was used as the aluminium based matrix for the investigation. The chemical composition of the aluminium alloy was determined using spark spectrometric analysis (SPECTRO Analytical instruments GmbH, Germany) with the results presented in Table 1. Rice husk ash (RHA), chemically pure silicon carbide (SiC) particles having average particle size of 30 µm purchased from PASCAL Scientific, Akure, Nigeria and copper nanoparticles (CuNP) having particle size of 40 nm [19] which was synthesized from Chemistry laboratory, Federal University of Technology, Akure, Nigeria were selected for the research.

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 |

### 2.2 PREPARATION OF RICE HUSK ASH

The rice husk ash is obtained by burning the rice husk inside drum with mesh. The ash obtained is conditioned at a temperature of 650 °C for 180 minutes in a muffle furnace to reduce volatile and carbonaceous constituents of the ashes. The ash was allowed to cool after which sieve shaker was used to sieve the ashes, with average particle size of 6.0 µm.

The chemical composition of the rice husk ash from this process is presented in Table 2.

### 2.3 Composites Production

The composites were produced via a two-step stir casting technique coupled with spin casting method as described by Talabi et al., (2019) [17]. This involves carrying out charge calculation to determine the quantities of rice husk ash, silicon carbide and copper nanoparticles needed to produce aluminium based composites. Weight ratios of mixed rice husk ash, silicon carbide and copper nanoparticles reinforcing phase produced were shown in Table 3.

Table 2. Chemical Composition of Rice Husk Ash

| Compound | Formulae | % Composition |
|---|---|---|
| Silicon Oxide | $SiO_2$ | 84.35 |
| Aluminum Oxide | $Al_2O_3$ | 0.53 |
| Ferric Oxide | $Fe_2O_3$ | 0.14 |
| Titanium Oxide | $TiO_2$ | 0.02 |
| Calcium Oxide | $CaO$ | 0.49 |
| Lead Oxide | $Pb_2O_5$ | 2.45 |
| Magnesium Oxide | $MgO$ | 0.54 |
| Sulphide | $SO_3$ | 0.12 |
| Sodium Oxide | $Na_2O$ | 0.35 |
| Potassium Oxide | $K_2O$ | 2.28 |

Table 3: Sample Designation and Reinforcement Weight Ratio

| Designation | % Composition | | | |
|---|---|---|---|---|
| | Al6063 | RHA | SiC | CuNP |
| A3R1S | 96 | 3 | 1 | |
| A3R1S1C | 95 | 3 | 1 | 1 |
| A3R1S2C | 94 | 3 | 1 | 2 |
| A3R1S3C | 93 | 3 | 1 | 3 |
| A3R1S4C | 92 | 3 | 1 | 4 |

Preheating of the RHA and silicon carbide 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 silicon carbide 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, silicon carbide and CuNP. Fettling operations were carried out on the produced samples and samples machined for test.

### 2.4 Density Measurement

Density measurements were carried out to study the effect of the RHA-SiC-CuNP varied 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 each weight ratio of RHA-SiC-CuNP reinforced composite produced [20]. The experimental density for each composite was evaluated by weighing the test sample using a high precision electronic weighing balance HUAZHI (Fujian) Electronic Technology Co., Ltd, China 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 Eq.1:

$$\rho_{Al6063/Gr/RHA/CuNP} = Wt_{Al6063} * \rho_{Al6063} + Wt_{RHA} * \rho_{RHA} + Wt_{SiC} * \rho_{SiC} + Wt_{CuNP} * \rho_{CuNP} \quad (1)$$

where:

- $\rho_{Al6063/Gr/RHA/CuNP}$ - the composite density
- $Wt_{Al6063}$ - the weight fraction of Al6063 alloy
- $\rho_{Al6063}$ - the density of Al6063 alloy
- $Wt_{RHA}$ - the weight fraction of RHA
- $\rho_{RHA}$ - the density of RHA
- $Wt_{SiC}$ - the weight fraction of SiC
- $P_{SiC}$ - the density of SiC
- $Wt_{CuNP}$ - the weight fraction of CuNP
- $\rho_{CuNP}$ - the density of CuNP

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

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

where:

- $\rho_{TE}$ - theoretical density (g/cm$^3$) and
- $\rho_{EX}$ - experimental density (g/cm$^3$).

### 2.5 Hardness test

The hardness of the composites was evaluated using EMCO Test DURASCAN Microhardness Tester equipped with ecos workflow ultra-modern software manufacture in Austria. These were measured by applying a direct load of 100 g for 10 seconds on flat smoothly polished specimens of the developed composites. This hardness test was in accordance with the specification of ASTM E384-11 standard [21] conducted on the prepared composite samples. The hardness of the composites was measured by applying a direct load of 100 g for 10 seconds on flat smoothly polished plane parallel specimens of the composites. Numerous hardness tests of five measurements were carried out on each samples and the average value was taken as a measure of the hardness of the specimen within the tolerance of ± 2%.

### 2.6 Tensile test

Standard procedures were used on the composites in accordance with ASTM E8M-15a standard [22] to determine their tensile strength. The samples for the test were machined to dimensions of 6 mm diameter and 30 mm gauge length. The test was then performed at room temperature with the use of a universal testing machine which was operated at $10^{-3}$ s $^{-1}$ strain rate. The tensile property evaluated from the tensile test was ultimate tensile strength.

### 2.7 Impact Test

Impact testing machine (Hounsfield Izod Impact Testing Machine, Serial No 3816) was used to evaluate the impact toughness of the machined samples, the specimens for each hybrid composites were machined to dimensions of 10 mm x 10 mm x 55 mm. 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 were calculated and recorded as the impact energy, this was done in accordance with ASTM E23 [23].

### 2.8 Microstructural characterization

Optical Microscope with Camera, Model Olympus DP 72 was used for detailed microstructural study of the developed composites. The specimens for the test were metallographically polished and etched with 1$HNO_3$: 1HCl solution before microscopic examination was performed

## 3. RESULTS AND DISCUSSION

### 3.1 Microstructure

Fig.1 shows the optical photomicrographs of the developed composites from Al6063 reinforced with RHA, SiC and CuNP. It was observed that the reinforcing particles were visible in the microstructure. The particles were fairly well distributed in the Al6063 matrix and signs of particle clusters were minimal.

### 3.2 Density Measurement

The measured density values by experimental and theoretical density for composites are compared and presented in Fig.2. It shows that sample A3R1S with experimental density of 2.627 g/cm$^3$ and theoretical density of 2.684 g/cm$^3$ has the least experimental and theoretical density lower than other composites. Sample A3R1S1C has experimental and theoretical density of 2.697 g/cm$^3$ and 2.746 g/cm$^3$ values respectively. The additions of copper nanoparticles to samples increased their densities. The density of sample A3R1S1C, A3R1S2C, A3R1S3C and A3R1S4C increases with increase in weight percent of copper nanoparticles added to the composites, this was as a result of copper nanoparticles density (8.9 g/ cm$^3$) higher than other reinforcing materials. From Fig 2, it can clearly be seen that the experimental and the theoretical density values were closed, this may be attributed to the rotational movement of the spin casting machine which allows escape of gasses during casting operation [17] and this confirms the suitability of double stir casting and spin casting techniques for composite preparation.

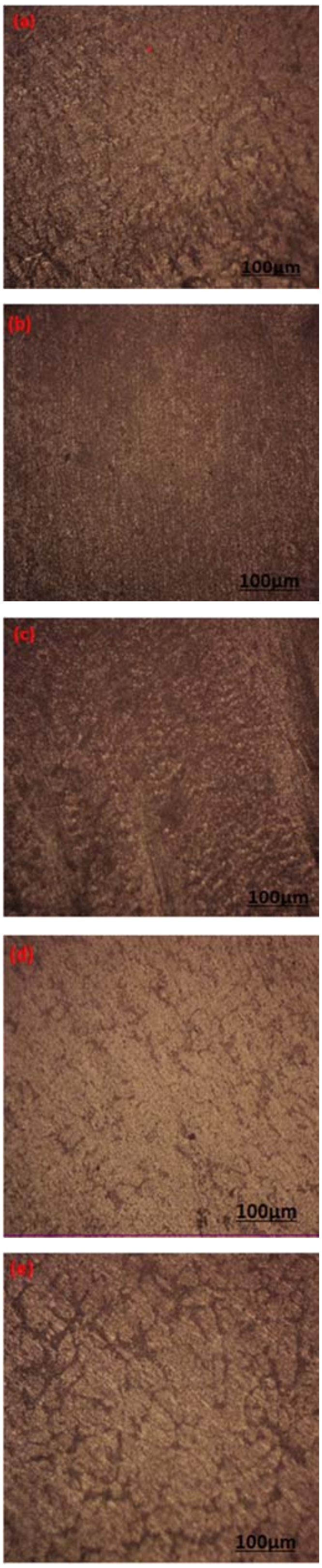


Fig. 1 *Photomicrograph showing (a) A3R1S (b) A3R1S1C (c) A3R1S2C (d) A3R1S3C (e) A3R1S4C*

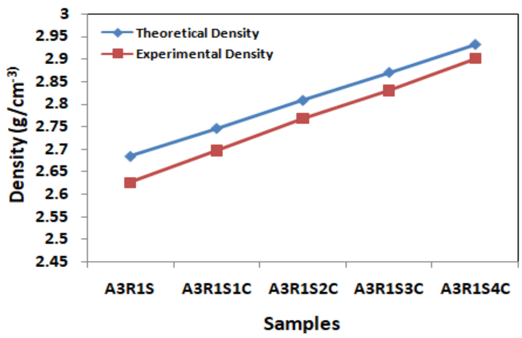


Fig. 2: *Density of the developed hybrid composites*

### *3.3 Porosity Measurement*

Fig.3 shows the porosity values for the developed hybrid composites. From the results, it was observed that the sample A3R1S4C has the lowest level of porosity while sample A3R1S has the highest value of porosity of all the developed composites. As copper nanoparticles in the composite increases, the porosity reduces and the density increases. The low porosity level was attributed primarily to the two-step stirring process adopted for producing the composites so also the spin casting technique which allows trapped gases to escape as a result rotational movement of the spin casting machine, thereby making the composites compact. The manual mixing operation performed in the semi-solid state helps to break the surface tension between the Al6063 melt and the particulates. This facilitates easier wetting and mixing of the particulates in the melt. The mechanical stirring operation and spin casting technique also contributed significantly to the reduction of reinforcing particles agglomeration and also improves the dispersion of the particulates [18].

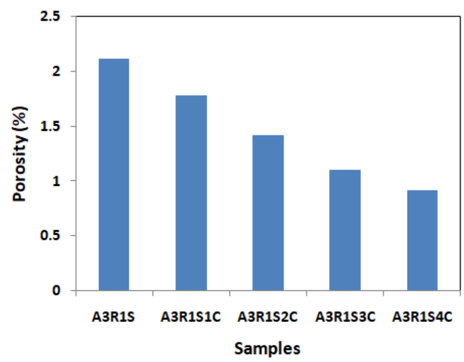


Fig. 3 *Percentage porosity for developed hybrid composites*

### *3.4 Hardness*

The hardness values of the hybrid reinforced composites were presented in Fig.4. From the results, it was observed that an improved hardness property was obtained in sample A3R1S1C (90 Hv) which was reinforced with rice husk ash, SiC and CuNP as compared to A3R1S (85 Hv), without the addition of copper nanoparticles. With the addition of copper nanoparticles from sample A3R1S1C to A3R1S4C, there was an improvement in hardness values of the composites ranged between 90 to 102 HV. As the copper nanoparticles increases from 1wt% to 4wt %, the hardness values increases [24], 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 [2]. Similar results were observed by Kumar and Birru (2018) [25] who investigated the characterization of Al-4.5%Cu alloy with the addition of silicon carbide and bamboo leaf ash, and exhibited higher hardness value as reinforcements increases. This is also in agreement with Mittal and Muni (2013) [26] who investigated the fabrication and characterization of mechanical properties of Al-RHA-Cu hybrid metal matrix composites and concluded that addition copper further increase hardness. Thus the addition of CuNP has significant effect on the hardness properties of the hybrid composite.

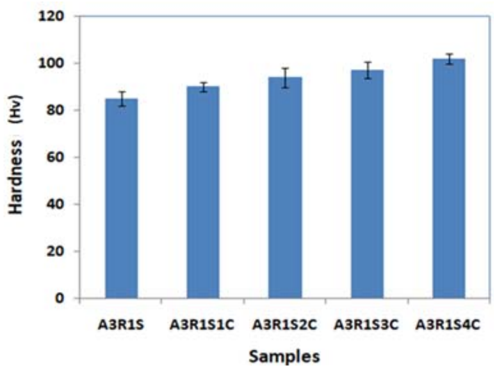


Fig. 4 *Hardness values for developed hybrid composites*

### 3.5 *Tensile Properties*

The ultimate tensile strength (UTS) of the developed composites was presented in Fig.5.

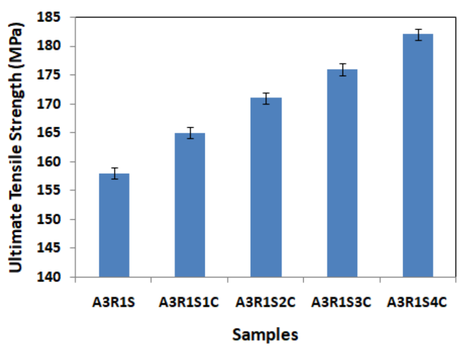


Fig. 5 *Ultimate tensile strength for the developed hybrid composites*

It was observed that there was an improvement in tensile strength of the composites. With incorporation of copper nanoparticles, there was increase in ultimate tensile strength with improvement of 11.2 %, from sample A3R1S to A3R1S4C and highest strength was found in A3R1S4C which has tensile strength value of 182 MPa. The strength of the composites increased as the presence of reinforcement particles increased due to the mechanisms of direct and indirect strengthening. The reason for improvement and increase in tensile strength may be attributed to direct strengthening which 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 [27, 28]. Indirect strengthening was also observed in the developed hybrid which arose from the thermal stress induced dislocations due to the significant difference in the thermal coefficient of expansion between the aluminium matrix and the reinforcement particulates. This resulted in increased resistance to plastic deformation and a higher work hardening capacity in metal matrix composites [29].

### 3.6 *Specific Strength*

The importance of RHA, SiC and and CuNP was better appreciated and showcased by the specific strength results in Fig.6. Specific strength is defined as the ratio of the UTS to the density of the hybrid reinforced composites. It was observed that the specific strength of the hybrid reinforced composite A3R1S was relatively higher than that of A3R1S1C this was as a result of its low density. The composite A3R1S4C has a marginal increase of 0.1 % as compared to A3R1S. With further addition of CuNP there was gradual increase in specific strength from composite A3R1S2C to A3R1S4C.

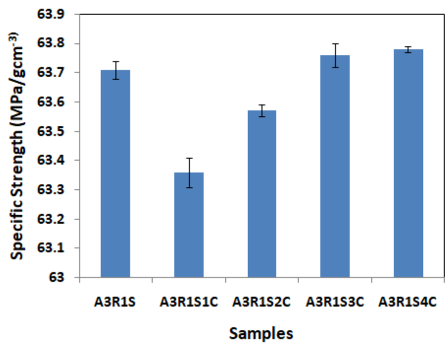


Fig. 6 Specific strength for the developed hybrid composites

### 3.7 *Impact Toughness*

Fig.7 displays the variation of impact toughness for the developed hybrid composites.

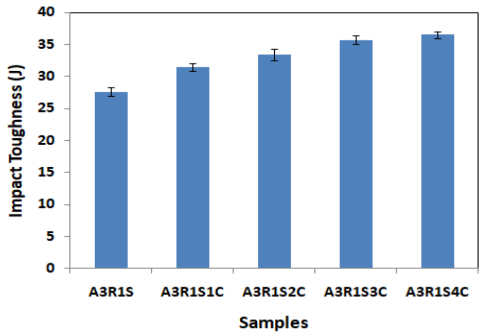


Fig. 7: *Impact toughness for the developed hybrid composites*

From the results obtained, the ability of the composites to absorb energy was improved with the reinforcements. The least impact toughness of the developed composites was A3R1S with impact toughness of 28 J without addition of copper nanoparticles. As the copper nanoparticles increases, the impact toughness of the developed composite increased by 14 % from composite A3R1S to A3R1S1C. Composite A3R1S4C has the most improved impact toughness of 37 J when compared with composite A3R1S that has no copper nanoparticles addition and this improvement may be attributed to good interfacial bonding between the matrix and reinforcements [30]. As porosity reduces with addition of CuNP, so also the impact energy increases.

## 4. CONCLUSIONS

The mechanical behaviour of Al6063 alloy matrix composites containing fixed rice husk ash (RHA), silicon carbide (SiC) and varied wt% of copper nanoparticles (CuNP) as reinforcements has been investigated. The following conclusions were drawn from the research;

As the density increases with the increase in addition of copper nanoparticles, the porosity reduces and hardness increases. The tensile strength obtained for the composites containing copper nanoparticles increases with increase in copper nanoparticles, while specific strength of the hybrid reinforced composite sample A3R1S was higher than that of sample A3R1S1C as a result of its low density

The composite A3R1S4C has the highest specific strength of 63.78 $MPa/gcm^{-3}$ as compared to other hybrid reinforced composites. The impact toughness of all hybrid composites containing copper nanoparticles was superior to that of the reinforced composite without copper nanoparticles.

The use of RHA, SiC and CuNP as reinforcement is viable for the production of high performance hybrid reinforced composites. CuNP can be used as reinforcement based on its overall positive effects on the mechanical properties of the composites even at high cost.

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