EFFECT OF CARBON NANOTUBE CONTENT ON THE MECHANICAL PROPERTIES OF (REINFORCED ALUMINIUM ALLOY METAL MATRIX COMPOSITES

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ABSTRACT

The paper presents the results of experimental investigations of CNT-Al 2024 alloy composites having 0.5 1 wt%, 1.5 wt%, 2 wt% and 2.5 wt% of CNT prepared through liquid metallurgy (stir cast) route. The com specimens were machined as per test standards. Some of the mechanical properties have been evaluate compared with Al2024 alloy. Significant improvement in tensile properties, compressive strength and ha are noticeable as the weight percentage of the CNT increases. The microstructures of the composites were s to know the dispersion of the CNT in matrix. It has been observed that addition of CNT significantly imp tensile strength along with compressive strength and hardness properties by 56, 61, and 9% respective compared with that of unreinforced matrix.

Keywords: CNT, Al 2024 alloy-matrix composite, Stir cast, mechanical properties.

1.0 INTRODUCTION

The reinforcement of aluminium alloys with carbon nanotubes has led to the generation of new engine materials with improved mechanical properties. Aluminium alloys attracts intense studies, owing to its density which results to several advantages in diverse areas of applications. (Esawi 2010). These alloys started to replace cast iron and bronze, in the manufacture high quality parts. CNT has been a good candida reinforcement in composites due to its outstanding mechanical properties, such as young modulus of 1 Literatures have shown enhancement of mechanical properties of metal matrices as a result.of addition of C Different methods has been used to disperse CNT into metal matrix. Powder metallurgy which is the preferred method of MMCs preparation due to its low processing temperature employed in mixing the powc quite costly and not applicable to complex shapes. Other manufacturing techniques such as squeeze, impregnation and spray casting methods are also constrained by certain disadvantages which include high co well as restricted size and limited shapes of the final product.

The present study takes advantage of stir casting technique which is proven to be more viable owing to simplicity, flexibility and ability to produce large sized and complex shaped component. It is also attrac because it allows a conventional processing route to be used and hence minimizes the final cost of the produ

Regarding aluminium matrix composites Kuzumaki et al. (1998) were the first researchers to show a 10 increase of the tensile strength adding 10 vol.% CNT, while a maximum of 129% increase in the tensile stre has been reported with the addition of 5 vol. % CNT addition (Deng, 2007). On the contrary, Salas et al. (20 have reported deterioration in hardness in a shock-wave-consolidated aluminium composite reinforced by 5 vo CNT composite. Agglomeration of CNTs in the matrix and weak interface bonding led to deterioration in properties. Noguchi et al. reported a 350% increase in the compressive yield strength in the case of 1.6 vol CNT addition, using the nanoscale dispersion method, which can provide a very satisfying dispersion a distribution of the reinforcements. by 5.45% and BHN value (Thomas et al., 2014). In this light an attempt l been made to develop CNT-Al 2024 alloy composites. An effort has been made in this paper to study mechanical properties of CNT-Al 2024 alloy composite by varying the wt% of the CNT.

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Abstract

The paper presents the results of experimental investigations of CNT-Al 2024 alloy composites having 0.5 wt%, 1 wt%, 1.5 wt%, 2 wt% and 2.5 wt% of CNT prepared through liquid metallurgy (stir cast) route. The composite specimens were machined as per test standards. Some of the mechanical properties have been evaluated and compared with Al2024 alloy. Significant improvement in tensile properties, compressive strength and hardness are noticeable as the weight percentage of the CNT increases. The microstructures of the composites were studied to know the dispersion of the CNT in matrix. It has been observed that addition of CNT significantly improves tensile strength along with compressive strength and hardness properties by 56, 61, and 9% respectively, as compared with that of unreinforced matrix

Introduction

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Materials and Methods

The matrix material used in this study is Al 2024 obtained from Scientific Equipment Development Institute, Minna, Nigeria. The CNT as presented in Plate 1 (16-50 nm diameter and approximately 33 µm length) was obtained from Center for Genetic Engineering and Biotechnology, Federal University of Technology Minna, Nigeria. Table 1 presents the chemical composition of un-reinforced Al2024 alloy.

Table 1: Chemical Composition of Raw Al- Cu Alloy

Elements	Al	Cu	Si	Fe	Ti	Cr	Ca	Ba	Pb	S
Percentage Composition (%)	95.432	4.112	0.204	0.149	0.021	0.02	0.02	0.002	0.002	0.038

Table 2: Mechanical Properties of Raw Al- Cu Alloy

Tensile Strength N/mm2	Compressive Strength N/mm2	Hardness (BHN)
100	205	69

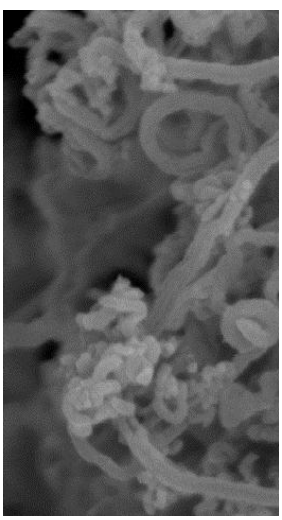

Plate 1: Scanning Electron Microscope Image Carbon nanotubes

The composite was prepared using stir cast experimental rig presented in Plate 2. The experiment commenced by melting 200g of Al 2024 alloy ingot in the cylindrical stainless steel crucible in the electric resistance furnace. Once the processing temperature of 690 ^{o}C of the first run was attained, the mechanical stirrer was switched to a speed of 500 rpm and lowered into the molten metal. A safe clearance of about 50mm was ensured between the impeller and the bottom of the crucible. MWNT (1.5wt%) was preheated at 200 ^{o}C for 30 min was gradually introduced into the molten metal using injection funnel while stirring continued for 150 secs. . The stirrer was raised at the end of the mixing and the mixture was poured into the prepared sand mould immediately. Digital thermocouple was used after the stirring to ensure that precise processing temperature was attained.

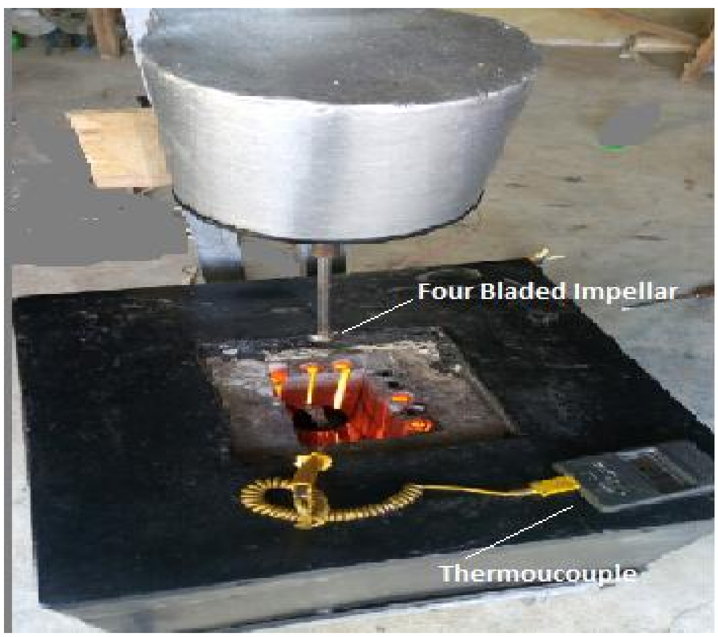

Plate 2: Stir-cast Experiment Rig

Tensile Test

Tensile testing was conducted using Dog-bone tensile test samples which were machined according to ASTM E8 standard. The testing was performed using 10kN Monsato Tensometer at a strain rate of 5 X 10^4 s^{-1}. The tensometer is equipped with data acquisition system which supplies the stress - strain curve during tensile test at room temperature. The test involves taking a sample of fixed cross-section area, and then pulling it by gradually increasing the force at a speed of 5 µm/s until the sample changes shape or breaks. The tensile test was carried out for all specimens respectively.

Compression Test

The compression test was also conducted using 10kN Monsato Tensometer, according to ASTM-E9 standard, the specimens of compression tests were prepared with diameter of 5 mm and guage length of 45 mm. in this case, the test involves gradual application of uniaxial force at a speed of 5 µm/s until the sample buckles.

Hardness Test

Brinnel hardness (BHN) test was conducted for all composite specimens. The specimens were machined to ASTM B724 standard which specified length and diameter of 10mm each. The hardness of the specimen determined by Brinell hardness testing machine with 20 kg load and 2 mm diameter steel ball indenter. The detention time for the hardness measurement was 20 seconds.

SEM of Produced Composite

SEM observation of the produced aluminum grains in composite was performed. In preparation for SEM imaging, the composite was cut into a half-moon shape and etched using nitric acid.

SEM samples were prepared by finishing the polished surface of the cross section of composites using a cross-section polisher.

Result and Discussion

Effect of CNT Weight Fraction Tensile Strength

The result obtained from the tensile test conducted to investigate the effect of CNT content on the tensile strength of the produce composite is presented in Figure 1. It is clear that the addition of CNTs results in an increase in strength at all CNT contents. It is observed that the addition of 2 wt% CNT provides the most significant strengthening of up to 50%. Further addition of CNTs (2.5 wt%) did not, however, contribute to a further enhancement.

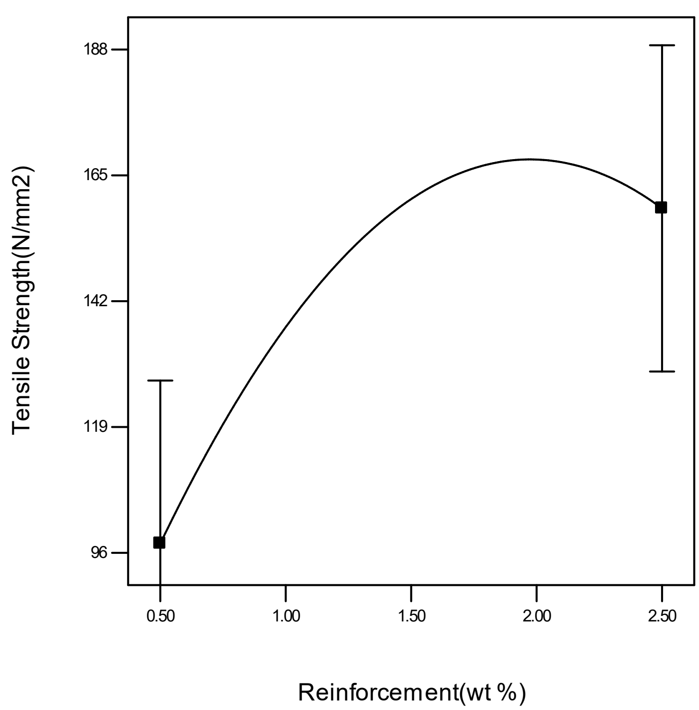

Figure 1: Effect of CNT Weight Fraction on Tensile Strength of Composite

The improvement in strength observed is also attributable to the behavior of nano size MWNT which serve as dislocation barriers. The increase in CNT weight fraction increases the number of dislocation barriers which further enhances strength. (Srinivasa, & Arvind, 2011). The decrease in strength at 2.5 wt% can be attributed to possible clustering of the CNTs at large volume fractions especially that the CNTs used in the present study have small diameters which make them difficult to disperse. In addition to poor dispersion, another factor expected to limit the strengthening and stiffening observed is the poor interfacial bond between the CNTs and the aluminium matrix which are observed to fail by CNT pull-out.

The conclusions made by various researchers on the tensile behaviour of Al – CNT composite varies greatly especially when different methods are used. Choi *et al.* (2009) reported the highest value of tensile strength of 629 MPa which was obtained through ball milling and hot-rolling process. Esawi *et al*. (2009) fabricated an Al–CNT composite coupling planetary milling and rolling process. In that case the maximum obtained tensile strength of the pure aluminium in presence of 0.5, 1 and 2 wt% CNT composite was increased by 10% compared to that of pure bulk aluminium. Esawi *et al*. (2009) also reported an approximately 50% increase in the tensile strength of the aluminium reinforced by 2 wt% CNTs prepared using the extrusion method.

Effect of CNT Weight Fraction on Compressive Strength

The effect of CNT weight fraction on compressive strength is presented in Figure 2. It can be deduced that the effect of CNT content on compressive strength of the composite also follow the same pattern as the tensile strength. The general trend shows that increase in CNT weight fraction result in increased compressive strength. This finding can be attributed to the possibility of load transfer to the homogenously dispersed CNT in the Al matrix. However, addition of CNT beyond 2wt% weight fraction lead to decrease in the compressive strength. This could be as a result of CNT clustering and formation of weak Al_4C_3 phase at higher CNT weight fraction which eventually lead to composite (Esawi *et al.,* 2010).

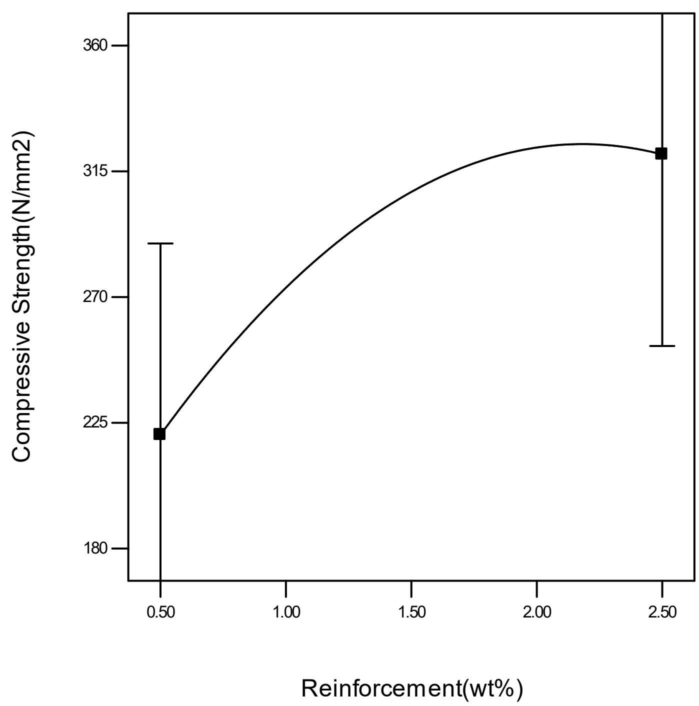

Figure 2: Effect of CNT Weight Fraction on Compressive Strength of Composite

Pure aluminium matrix composite reinforced by 2.5 wt% CNT was fabricated using unique equipment for spark plasma extrusion (SPE), and it is reported that the composite had a similar compressed strength value to that of the pure Al sample (Morsi, *et al.,* 2010).

Effect of CNT weight fraction on Hardness

The composite reinforced with 2wt% CNT revealed the highest value of hardness. Figure 3 indicated that the hardness values continued to increase steadily from run 1 at CNT weight fraction 0.5wt% until 2wt%.

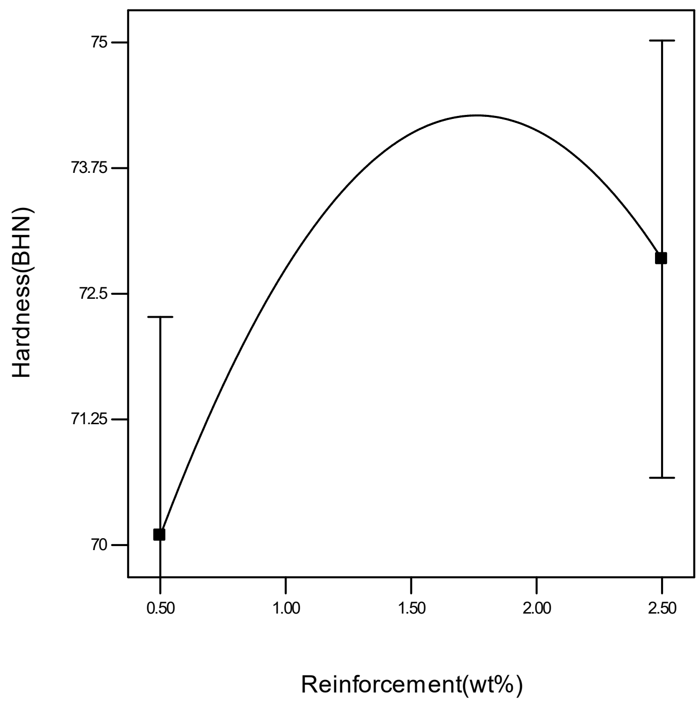

Figure 3: Effect of CNT Weight Fraction on Hardness of Composite

Further increase in CNT fraction only resulted in a weaker composite. This result is in agreement with the conclusion of Hamid *et al.* (2014) that CNT poses obstacles to dislocation movement which result in strengthening of composite by a mechanism known as Orowon looping. The low hardness value obtained at 2.5wt% is attributable to agglomeration of CNT due to high content of Al_4C_3. Similar observation was reported by Esawi *et al.* (2010).

SEM of Produced Composite

Sanning Electron Microscope Image/ EDS of CNT Reinforced Aluminium Alloy. The SEM micrograph of the produced composite is presented in Figure 3. Although it is difficult to view the CNT in the composite under the SEM image, however the accompanied EDS confirms its presence. The nanosized MWNT addition from 2 wt% lead to the refining of grains, making a coaxial finer grain structure than the matrix alloy.

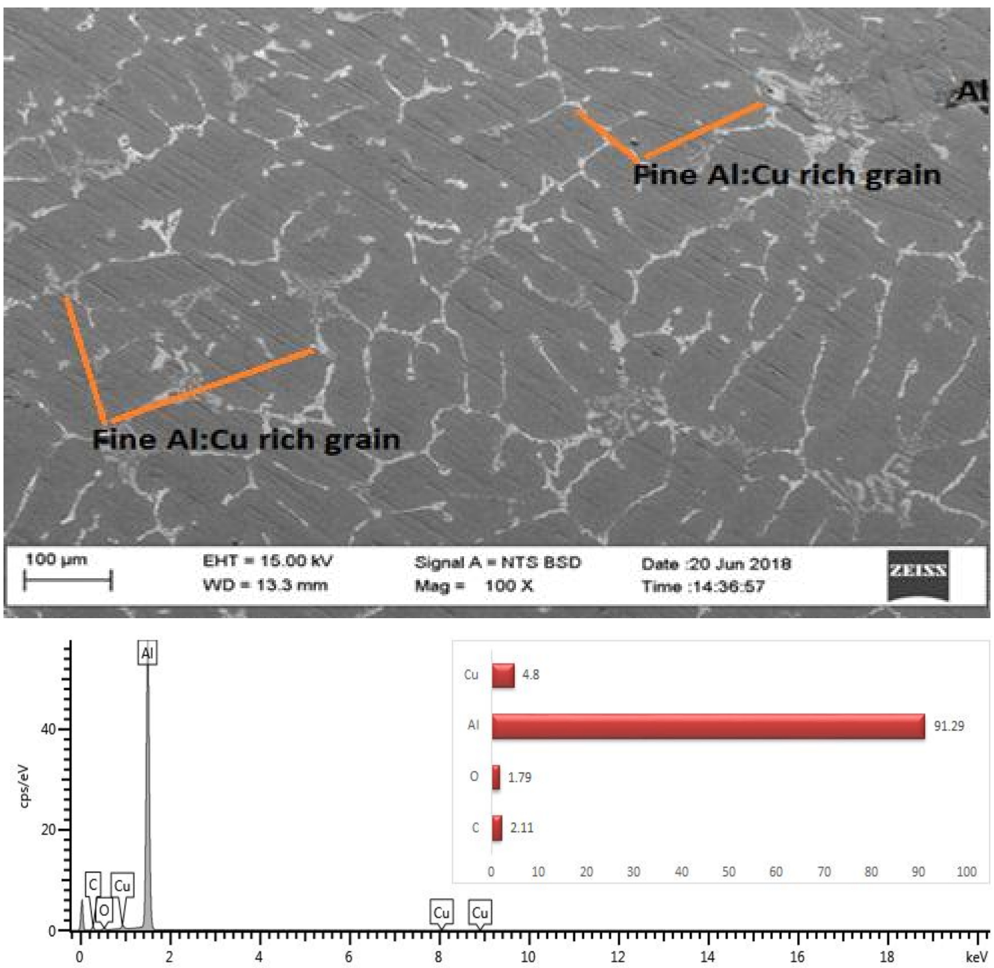

Plate 3: Scanning Electron Microscpe Image/ EDS of CNT Reinforced Aluminium Alloy

For nanocomposite materials, the grain size of the matrix depends on the particle size or the volume fraction of the particles. As the particle size decreases or volume fraction of nanoparticles increases, the grain size of the matrix decreases (Ezatpour *et al.,* 2014). This behavior is attributed to a higher incidence of grain boundary pinning which prevents grain growth. It has been observed that grain refinement occurs when a large amount of MWNT reinforcement is added to the matrix (Ceschini *et al.* 2013). Choi *et al.,* (2012) also reported the formation of ultrafine grained Al based MWNT composite. The well dispersed MWNT was observed to form strong interface with the matrix by mechanical interlocking.

Aside grain refinement, other possible strengthening mechanisms resulting from MWNT addition that could lead to the enhancement of the mechanical properties are load transfer, the thermal mismatch and orowon looping effects. (Esawi *et al.,* 2010)

Conclusions

Based on the experimental observations made in the present research, the following conclusions have been drawn. Al2024 alloy- matrix composites have been successfully developed with fairly uniform dispersion of CNTs. Addition of CNT significantly improves tensile strength of Al2024 by 56% when compared with that of unreinforced matrix. while the compressive strength and hardness of CNT-Al2024 composite were increased by 61% and 9%.

However, the mechanical properties decreased beyond 2wt% because at large weight fractions, the CNTs used in the present study were found to have a tendency to agglomerate and thus were difficult to disperse. The agglomeration has in turn affected the attained mechanical properties, which although were improved compared to un-reinforced aluminium alloy.

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