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Improved Mechanical Properties of AA5083 Reinforced with Multiwall Carbon Nanotubes for Automobile Applications

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ABSTRACT:

Aluminium alloys are widely used in automobile applications due to their good mechanical, corrosion and wear resistance properties. This work mainly focuses on the enhancement of mechanical properties of Aluminium alloy AA5083/MWCNT composites using a semi-solid state route (compo-casting method) and compare with the conventional AA5083 alloy. AA5083 and MWCNT microstructures were examined using field emission scanning electron microscope and energy-dispersive X-ray spectroscopy analysis. The experimental results showed an enhancement in the ultimate tensile strength and yield strength for the MWCNT reinforced composite compared to the corresponding values of AA5083. The Brinell Hardness of the MWCNT reinforced composite was better than the conventional AA5083.

KEYWORDS:

AA5083; Field emission scanning electron microscope; Tensile strength; Multiwall carbon nanotubes

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ACRONYMS:

CNT	Carbon nanotubes
MWCNT	Multiwall carbon nanotubes
FESEM	Field emission scanning electron microscope
ED-X	Energy-dispersive X-ray spectroscopy
CVD	Chemical vapour deposition

1. Introduction

From the references [1-4], the following three major reinforcing mechanisms are to be considered before mixing the nano particle into the matrix material as reinforcement to attain high strengthening effect:

1. Orowan mechanism: When the number of particles increases in certain volume fraction, the inter-particle spacing is smaller and yield for smaller particles of reinforcement will occur;
2. Thermal mismatch: A high difference for the coefficient of thermal expansion, between the reinforcement and the matrix will create higher dislocation density around the reinforcement; and
3. Load transfer: As much stronger and high aspect ratio of the reinforcement, the load can be transferred efficiently.

Multiwall carbon nanotubes (MWCNT) were selected as reinforcement material based on the above reinforcing mechanisms and CNTs has excellent mechanical properties [4].

Arc-discharge and chemical vapour deposition (CVD) methods were used to manufacture MWCNT. CVD-MWCNT is the mainly used material for an industrial level and large quantities can be produced. Compared to the Arc-discharge MWCNT, CVD-MWCNT is cost effective [5-12]. In contributing to the composite mechanical properties CNT weight fraction, aspect ratio, size orientation and interfacial bonding play a major role [4]. The purity and density of MWCNT also plays a vital role in the composites. Many researchers suggest that the MWCNT of 1.5 wt% is an optimal value to achieve an enhanced mechanical property with improved hardness. Addition of MWCNT by 2 wt% increases the strength by 50% and Young's modulus by 23% [8]. When MWCNT content goes beyond 1 wt%, clusters were formed in the processed composite which often lead to reduction in the strength and stiffness [13].

Low wet-ability is the core issue for nano particles to produce the MWCNT by usual casting processes. For an optimal strengthening potential, the small powder aggregates are prone to produce cluster which the dispersion will not be homogeneously in the matrix. In order to overcome this problem, different alternative techniques have been proposed. In this work, the mechanical properties and characterization of material were studied. To produce the aluminium metal matrix composites, compo-casting method was used to achieve uniform distribution of the MWCNT.

2. AA508/ MWCNT composite fabrication

AA5083 alloy base material chemical composition is given in Table 1. MWCNT is used as reinforcement. In this work, purity of MWCNT is >95 - 98%, diameter (D) is 5 - 20 nm and length is 1 - 10 μm. It was manufactured using CVD method [4-8]. The AA5083/MWCNT composite was prepared by semi-solid compo-casting method. Fig. 1 shows the experimental setup of stir-casting equipment used to produce the AA5083/MWCNT composite. Five specimens were fabricated. The composites are processed with 500g of AA5083 alloy and MWCNT in the varying compositions like 0%, 1%, 1.25%, 1.50% and 1.75% by weight (wt%). About 500g of the AA5083 was melted at 680°C in a crucible in an electrical resistance furnace. After complete melting, an argon gas was passed to prevent hydrogen entrapment during melting process. Using a K-type thermocouple, the semisolid temperature of 590°C was measured. The AA5083 alloy was cooled to the same temperature. Due to the existence of Mg in the matrix material, better wet-ability of the nano particle was achieved. AA5083/MWCNT blocks introduced into the melt and stirred for 2-3 minutes in semisolid state. During the semi-solid state, the preheated MWCNT was added along with the matrix material for uniform dispersion. The molten metal was poured into the mould.

Table 1: Chemical composition of Aluminium alloy AA5083 [11]

Constituent	Content %	Constituent	Content %
Al	Balance	Mn	0.4-1.0
Mg	4.0-4.9	Zn	0.25
Si	0.4	Ti	0.15
Fe	0.4	Cr	0.05-0.25
Cu	0.1	-	-

Fig. 1: Measured MWCNT (left); Compo-casting setup (right)

3. Result and discussion

3.1. Microscopic analysis

Using high resolution FESEM, MWCNT as shown in Fig. 2 is analysed. The size of the MWCNT is 5nm in mean diameter, 1µm in mean length and 98% of purity. Fig. 3 shows the ED-X analysis of MWCNT and the strong reflection peak was found in between 12° - 28°. The peak in the ED-X pattern of MWCNT showed the cylindrical nature of grapheme sheets nested together and it is in multiwall nature [13]. The presence of various structures in the AA5083/MWCNT sample is assessed for various composition of MWCNT wt%. Figs. 4 and 5 show the FESEM images of AA5083 alloy, after being added with MWCNT by compo-casting method to increase the uniform dispersion of MWCNT. Thus, the AA5083 and MWCNT mechanical interaction has been achieved. The surface morphology of the cast AA5083/ MWCNT composite with a particle uniform dispersion and a minimum amount of cluster formation of MWCNT was observed.

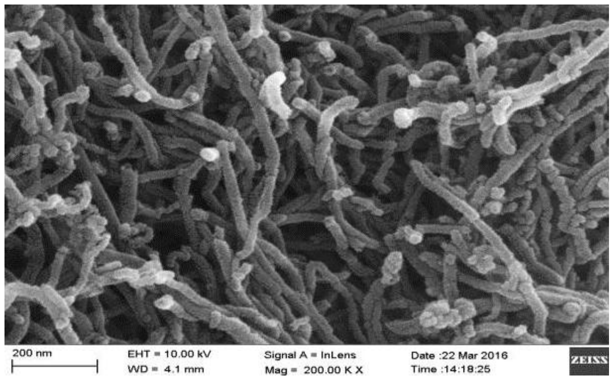

Fig. 2: Micro-structure of MWCNT at magnification of 200 K X

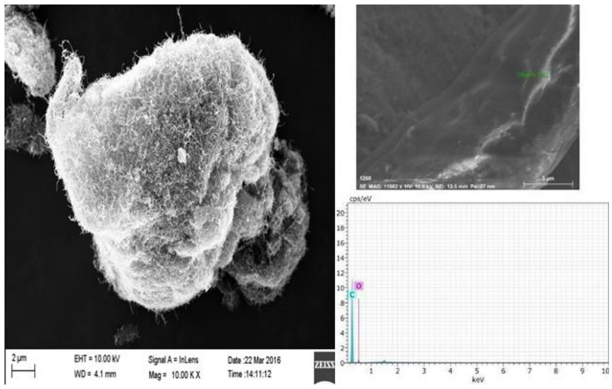

Fig. 3: ED-X pattern showing the cylindrical nature of grapheme sheets nested together

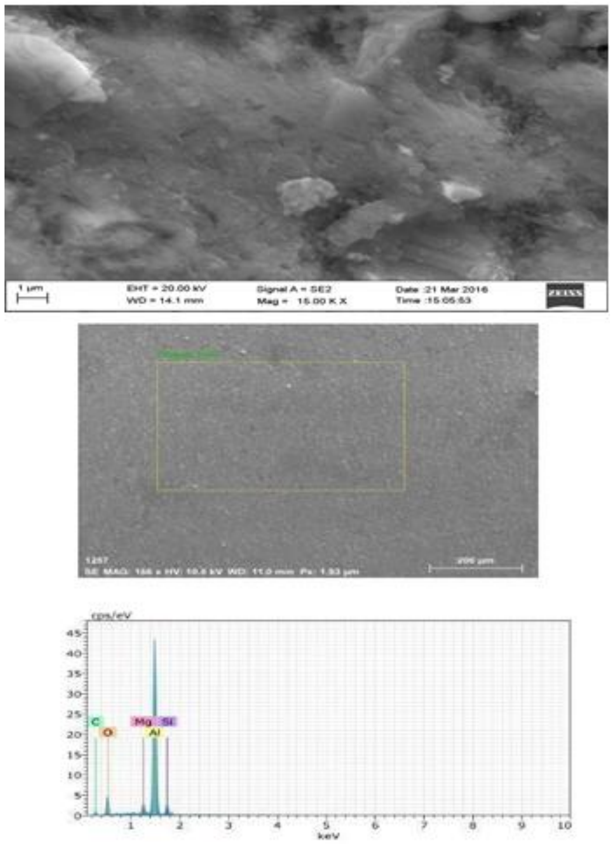

Fig. 4: ED-X of 1 wt% MWCNT with strong reflection peak

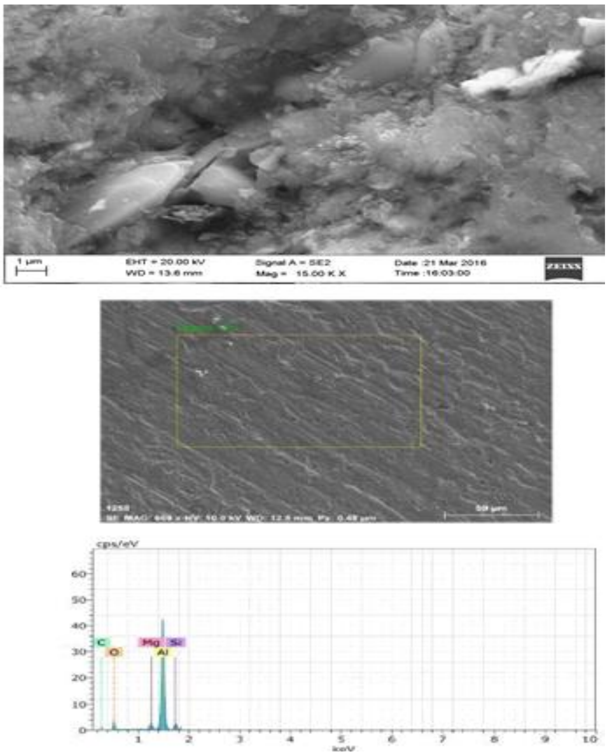

Fig. 5: ED-X of 1.75 wt% MWCNT with strong reflection peak

3.2. Mechanical characterisation

Fig. 6 shows the influence of adding MWCNT into AA5083 alloy on the Brinell hardness with varying weight fractions. Based upon the increase of hardness of the material it can be concluded that the reinforcement was uniformly dispersed in a matrix material [14]. It is a method to predict the homogeneous dispersion of CNT in the matrix material. Compared to normal AA5083 alloy the hardness value of MWCNT reinforced composite material was increased due to strengthening and hardening of the matrix material that was improved by increasing the dislocation density of the matrix alloy during solidification and variation in the co-efficient of thermal expansion between MWCNT and AA5083. The grain size of the AA5083 matrix of the composite samples may be decreased partly by adding MWCNT. Fig. 7 shows the density of the composite materials and matrix alloy as measured using Archimedean density (water displacement approach) according to ASTM B311-08 [14]. There is no much difference in the density value of composite material and matrix material. Due to the fine particulates of the MWCNT, the density is within the limit of 2.669 g/cm^3.

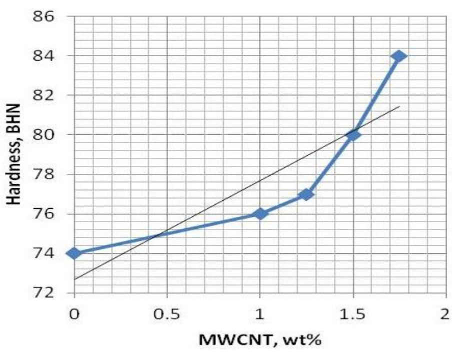

Fig. 6: Hardness vs. MWCNT

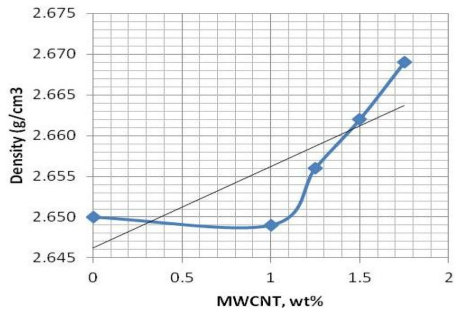

Fig. 7: Density vs. MWCNT wt%

The tensile test was conducted in accordance with the ASTM-A370 standard. Tensile specimens with a gauge length 32 mm, height of 10 mm and thickness of 5 mm were used. The specimens were machined using a Wire-EDM machine. The tensile tests were carried out in TUV Rheinland (India) Pvt. Ltd., Coimbatore. Figs. 8 to 10 show the ultimate tensile strength, yield strength and elongation of AA5083 and AA5083/MWCNT composite with different weight percent of MWCNT. Researchers say that ultimate tensile strength value at 1.5wt% MWCNT is the optimal value for the CNT reinforced Aluminium MMC, but 1.75wt% MWCNT shows increased ultimate tensile strength than the optimal value in the present work. The yield and ultimate tensile strengths of the composite material were enhanced concurrently compared to the base matrix alloy. For 1.75 wt% of MWCNT, the ultimate strength has increased to a value of 237 MPa from 168.28 MPa. The increased mechanical properties clearly states, MWCNT is anisotropic in the composite.

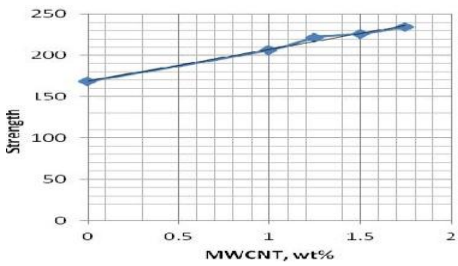

Fig. 8: Ultimate strength (MPa) vs. MWCNT wt%

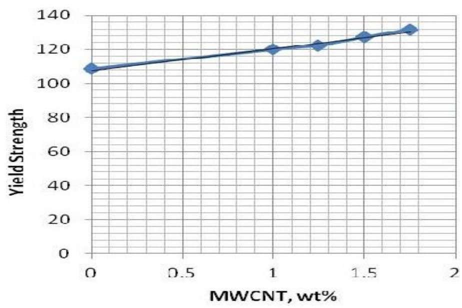

Fig. 9: Yield strength (MPa) vs. MWCNT wt%

The elongation was reduced continuously, when MWCNT proportion is increased to 1.75wt%. Similarly the strengthening of AA5083/MWCNT composite was at maximum. For low temperature applications, the percentage of elongation should not be lesser than 5% [14]. The elongation percentage for AA5083 / MWCNT composite lies between 7-12%. Therefore, for low temperature applications the optimal MWCNT lies between 0.5 to 1.75 wt% in order to get a better ductility and strength even at low temperature. Therefore, Carbon nanotubes can be used as an effective reinforcement for fabricating AA5083/MWCNT composite for low temperature applications.

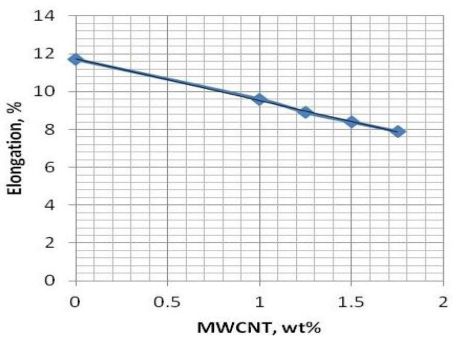

Fig. 10: Elongation vs. MWCNT wt%

4. Conclusion

From the presented experimental results and analyses of this work, the following conclusions are drawn:

- Adding MWCNT reinforcement in the matrix material increases the mechanical properties to a considerable level by 36% for fabricating automobile components.
- Brinell hardness value of the composite material was increased from 74 BHN to 84 BHN.
- Density of the composite material was within the limit of 2.669 g/cm^3, in terms of weight it is an advantageous factor.
- By reducing grain size of the MWCNT and increasing the weight fraction of MWCNT up to 1.75wt%, the ultimate tensile strength and yield strength were found to be increased considerably, due to the presence of carbon the percentage elongation got decreased.
- MWCNT can be added up to 1.75wt% with the matrix material, with increase in mechanical properties of the composite.

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