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Fabrication and Analysis of Aluminium based Nano Composites Reinforced with Carbon NanoTubes

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Abstract: Multi-walled carbon nanotube reinforced with aluminiummetal matrix Nano composites are attractive for their superior mechanical properties compared to the wrought aluminium alloys which has a prominent use in structural applications.Mechanical properties of Al-CNT are analyzed to understand the effects of CNT dispersion, processing technique, and CNT matrix on elastic modulus, strength and toughness of composite. Strengthening mechanisms shows decreasing strengthening effect with an increase in CNT content. The strengthening effect is highest for CNT content less than 2% wt. As enhancement of up to 50% increase in tensile strength and up to 23% increase in stiffness compared to pure aluminium were observed. This paper concludes that usage of MWCNT in aluminium alloy is more technically and economically a better method to obtain a significant increase in the mechanical properties to an extent, which cannot be obtained economically by any other means.

Keywords—metal matrix composites; carbon nanotube; microstructure; powder metallurgy;

1. INTRODUCTION

Carbon nanotubes (CNTs) are arrangement of single or multiple graphite sheets into a seamless cylinder. These are defect free Nano sized reinforcement material that are light in weight with a hollow core and an immense aspect ratio. The admirable mechanical properties of CNTs like the elastic modulus of ~1 Tera Pascal and tensile strength in range of ~150 GPa makes its application in the wide range of fields like conductive polymers and composites, sensors and instruments, electromagnetic shielding,sporting goods [1-4].The strong sp2 bonding between the C-C bonds results in high strength of the structure.For the application of CNTs in structural fields, the CNTs are dispersed with either Al or Cu. CNT composites are generally fabricated by different processing methods which can be classified as 1. Powder metallurgy technique, 2. Melt processing technique, 3. Electrochemical technique, 4. Thermal spraying etc.In this study, carbon nanotube (MWCNT) reinforced with aluminium composite is fabricated and the mechanical properties and the electrical conductivity of the composite was studied [7]. Powder metallurgy technique has been adopted in fabrication of the composite. The CNTs are blended with the Al powder and are sonicated at a certain frequency. The green mixture obtained is compacted in a die under pressure and then sintered under a controlled atmosphere to bond the particles metallurgically which develops the desired properties [6]

Kuzumaki et al.[8] obtainedthe yield strength of 80 MPa for 5–10 vol% CNT whereas Deng et al.[10] reported yield strength of 336 MPa for mere 1 wt% CNT addition to Al matrix. The tensile properties of CNT reinforced aluminium composites synthesized bydifferent processes display a wide scatter in the mechanical properties attributed to the variance in the microstructural features, defects, porosity level caused by processing and lack of consistency inmechanical testing techniques [12].The nanocomposite exhibits retention andhomogenous distribution of MWCNTs in Al–Si matrix[11]. In thepresent effort,tensile tests have been machined out of the cylindrical Al–Si nano-composite structure reinforced with MWCNTs. Uniaxial tensiletesting has been carried out to evaluate stress–strain behaviour.The experimental values of ultimate tensile strength were compared with theoretically computed values based on fibre pull outtheory[13]. Additionally, the aim of this investigation is to evaluate the mechanical properties of ‘‘large” CNT reinforced aluminium nanocomposites from the viewpoint of constitutive hierarchicalmicrostructure, to bridge the relationship among mechanical properties, and macro/nano scale microstructure. Large scale mechanical testing is critical for the success of nanocomposite and nano-structured materials for real life engineering applications.

2. POWDER METALLURGY

Powder metallurgy is a quite easy method of manufacturing some basic shaped components by blending elemental or pre-alloyed powders together, compacting this blend in a die, and sintering or heating the pressed part in a controlled atmosphere furnace to bond the particles metallurgically. The powder metallurgy process is a different part manufacturing method that is highly reliable and cost effective in producing simple or complex parts at, or close to final dimensions. Powder metallurgy provides the following advantages.

- Production of complex shapes to very close dimensional tolerances, with minimum loss in the raw materials.

- Physical and mechanical properties of the components can be obtained together through close control of starting materials and the process parameters.
- Properties can be improved through secondary processing operations such as heat treating and cold/hot forming.

3. PROCESSING METHODOLOGY

Carbon nanotube reinforced Aluminum metal matrix composites are prepared through a variety of processing techniques. Powder metallurgy is the most popular and widely applied technique for preparing MWCNT composites.

Most of the studies on Al-CNT composites have been carried out by the process of powder metallurgy. The basic processing methods in powder metallurgy are

1. Sonication of CNT.
2. Mechanical alloying of Al powder and CNT
3. Drying the mixture
4. Compaction of the green mixture
5. Sintering

4. EXPERIMENTAL PROCEDURE

Three specimens of 2.5wt.%, 0.5wt.% and 1wt.% of CNT (average dimensions: 140 nm, 4-8 nm internal diameter, and 3-4µm in length) for 8.5 grams of Al (99.7%pure,-200 mesh, Aluminum powder), is taken in jars with 50 ml acetone solution and is sonicated under the ultrasonic frequency of 68KHz for half an hour, the sonication is performed to disperse the CNT in the acetone equally, and the three specimens are mixed with 8.5 grams of aluminum powder each and again sonicated under same frequency for another one hour till a equally dispersed precipitate of Al-CNT is obtained. The obtained precipitate is dried in an oven for 12 hours under the temperature of 80^0C to make sure the entire acetone is evaporated and the mixture is free from moisture.

The obtained green mixture is pulverized to disintegrate the accumulated mixture of Al-CNT. The pulverized mixture were compacted in 20mm diameter compaction die at 550 MPa. The obtained compacted Al-CNT component is sintered under the nitrogen medium at a temperature of 500^0C for about 1 hour.

The mechanical response of the processed materials was characterized using the Vicker's Micro-hardness tester at a load of 500grams and Dwell time of 15 second. The samples were mounted using bakelite due to its lower elasticity compared to epoxy resins. The samples were ground and polished to 1µm and micro structural examination were done by etching them in Keller's solution. and the microstructures were characterized under the magnification of 150X, 250X and 450X. The sample preparation was carried out by conventional grinding and polishing techniques.

5. RESULTS

The effect of carbon nanotubes content on hardness is shown in Fig. it is proved that with small amount of carbon nanotube reinforcement, the hardness increases with the increase in the content of carbon nanotube, whereas the large amount of carbon nanotubes reduce the hardness. this could be due to the filling up of micro voids by the CNT resulting in increase in strength, however, the large amount of CNT is prone to mix up together in the 2014 Al powders. CNT agglomeration becomes the defect source. hence the hardness of composites decreases with the increase in the amount of CNT in the composites.

Specimen	**Vicker's Micro Hardness Number**	**Tensile Strength**
0.25wt%CNT + Al	48.075	471.5 MPa
0.5wt% CNT + Al	53.125	521 MPa
1.0wt% CNT + Al	53.525	524.9 MPa

Table 1: Vicker's Micro Hardness and Tensile Strength of the Specimens

The table 1 shows that the maximum tensile strength value of 524.9 MPa is obtained at 1.0wt%CNT and those are enhanced by 35% compared with the matrix material Al 2014 fabricated by same process. This phenomenon can be due to the factor that with the addition of very small amount of CNT, CNTs are distributed uniformly in the voids resulting in the increase in the relative density of the composites. Moreover, the bonding between CNT in the conglomeration is very weak, leading to the deterioration in mechanical properties.

From the literature survey, the tensile strength and Young's modulus it is evident that increases with increase in the content of CNT when the content is less than 1.0wt%, and decreases obviously with increasing CNT.

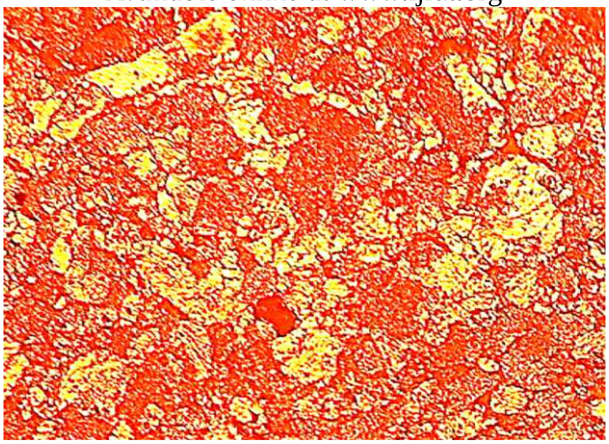

Fig 1: 0.25wt%CNT + Al etched (450X)

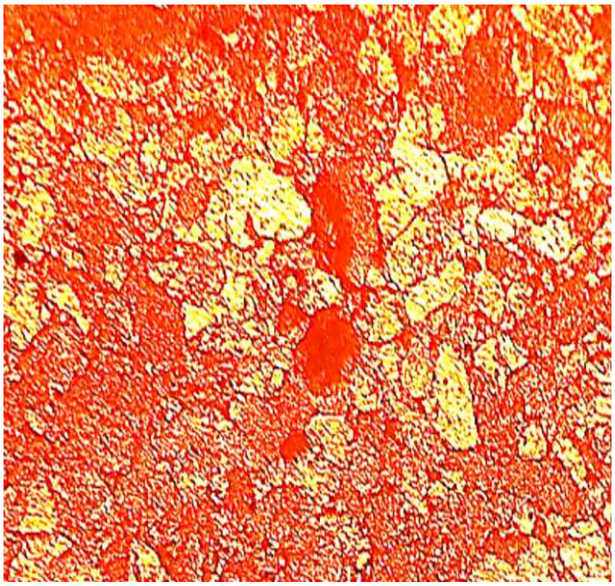

Fig 2: 0.5wt% CNT + Al etched (450X)

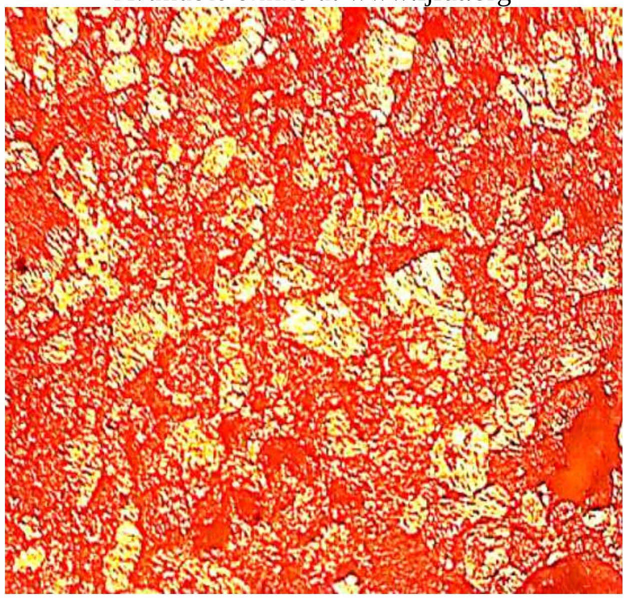

Fig 3: 1.0wt% CNT +Al etched (450X)

The electrical conductivity of three specimens at room temperature were analysed and observed that the resistivity of the component is decreasing with the increase in the percentage composition of the CNT in the composite.

Composite	Resistivity (Ωm)
Al + 0.25% CNT	0.0817215
Al + 0.5% CNT	0.068996
Al + 1.0% CNT	0.0335

Table 2: Electrical Resistivity of the Composites

6. CONCLUSIONS

The results are evident that the mechanical properties like hardness, Tensile strength of Al 2014 - CNT composite are improved. With the increase in tensile strength the increase in the Young's modulus of the material can be estimated. The increase in the tensile yield strength could imply the applicability of OROWAN LOOPING to the composite system. Hence the strengthening mechanisms could be due to the synergetic effect of SHEAR LAG and OROWAN LOOPING. However, the MICRO STRUCTURE images do not reveal any direct evidence for these mechanisms. The Al+CNT were analysed for electrical conductivity, the electrical conductivity increased considerably with the increase in the composition of CNT in the composite.

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