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Research paper

Investigation of flexural and impact strength of carbon nanotube reinforced AA7075 metal matrix

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Abstract

Metal matrix nano-composites are grabbing more attention by many researchers in the recent years as they exhibit outstanding properties when compared to pure metal alloys. In the present study Aluminium Alloy 7075 was selected as the matrix and carbon nanotubes was selected as reinforcing element to investigate the percentage enhancement of flexural strength and impact strength of metal matrix composite. Stir casting process was selected to fabricate the specimens. The multi walled carbon nanotubes with different weight percentages (0.5, 1.0, 2.0, 5.0 wt %) were selected to prepare the AA7075-CNT metal matrix composite. Microstructure and dispersion of CNT was examined using Scanning Electron Microscope (SEM) with EDX. The experimental results of mechanical tests showed that if the MWCNTs particle content increases considerably flexural strength and impact strength also increases about 125% and 90% respectively. Thus the AA7075-CNT metal matrix can be used in automobile and aerospace applications under high load conditions.

Keywords: *Carbon Nanotubes; AA7075; Stir Casting; SEM; Impact Strength; Flexural Strength.*

1. Introduction

Nanotechnology makes it possible to create new materials and devices with a vast range of applications in the field of medical science, electronics, biomaterials, energy production, aviation departments and automotive sectors. Researchers are showing great interest in reinforcing carbon nanotubes (CNT) in metals over the past few years. Especially they have been concentrating on the enhancement of mechanical and thermal properties of metal matrix due to reinforcement. Mechanical properties of carbon nanotubes have attracted the attention of many researchers since their discovery in 1991 [1]. Carbon nanotubes became important reinforcements for metals and alloys as they have a very high strength and very high Young's modulus [2-3].
The hardness value of composite (MWCNTs/Al) depends highly on mass density, weight percentage of f-MWCNTs, milling time and also fine structure of nano-composite [4]. Multi-walled carbon nanotube reinforced Al composite powders were successfully fabricated by a novel wet shake-mixing technique without introducing significant deformation or defects to the MWCNT with uniform distribution and the cylindrical structure of MWCNT is useful for improvement of overall properties of composite[5]. Mechanical property enhancements of the Al--CNT composites from polyester binder-assisted (PBA) and high energy ball milling were superior to that mixed by low energy ball milling [6]. The macro hardness (HV20) was measured for aluminium and 1 to 9 wt% Multi Walled Carbon Nanotubes (MWCNTs) composites that were milled and hot compressed. The hardness increases with increasing fraction of MWCNTs up to 6 wt % (HV20 = 151) and then remained constant [7]. Compared to that of unreinforced aluminium, the yield strength of 1 wt. % and 3 wt. % CNT/Al composites increased by 23.9% and 45.0% respectively [8]. Upon addition of MWCNTs upto 2 vol. %, relative density remained at 98%, and hardness increased to 245 HV. Compressive strength of nano-composites found a maximum value of 810 MPa at 2 vol.% MWCNTs addition which is 78%, 34% and 12% greater than that for Al2024–O, Al2024–T6 and nanostructured Al2024 respectively[9]. Induction melting, a distinct approach to facilitate the dispersion of CNTs in molten aluminum which gives refinement in crystallite size (320 nm) and increase in lattice strain (3.24×10^{-3}) and simultaneous increase in yield strength (77%), tensile strength (52%), ductility(44%) and hardness (45%) was observed[10]. Nano indentation testing on the composite with dispersed MWCNTs indicated an increase in Young's modulus by 21% and 22% and an increase in the nano hardness by 43% and 54% by the addition of 1 wt% and 2 wt% copper coated MWCNTs respectively[11]. The yield strength and ultimate tensile strength of the composites significantly increased, when the ball milling time increased from 2 to 12 hours, finally reaching about 210 MPa and 253 MPa respectively, for the composite milled for 12 hours [12]. With increase of MWCNT content, the tensile strength and micro hardness of MWCNTs/Al composites gradually increases, but on the contrary, the elongation decreases. The maximum ultimate tensile strength reached up to 190.2 MPa when 6 vol. % MWCNTs were added, and this value was two times more of that of aluminum matrix [13]. The yield strength and tensile strength of pure aluminium sample were measured as 90 and 136 MPa, respectively. These values were increased to 110 and 170 MPa for semi-wet (SW) sample and improved to 152 and 203 MPa for

slurry based (SB) product, by adding 1.5 wt.% CNT to pure Al[14]. Weak interfacial bonding between CNTs and Al matrix is a critical issue for maintaining high strength and good ductility. This can be achieved by non-equilibrium interface and it increases the mechanical properties [15]. The composite (Al/MWCNTS) containing the MWCNTs shows a good strength but it shows poor electrical and thermal conductivities. If the composite is milled at 100 rpm for 2 hours it enhances the electrical and thermal conductivities [16]. The composite consisting of multi-walled carbon nanotubes (MWCNTs) in an aluminum (Al) matrix was fabricated by mechanical alloying. The macro-hardness confirmed the improvement in the mechanical properties due to the addition of MWCNTs to the aluminium matrix [17]. The mechanical properties of MWCNT/AA5083 composites fabricated by powder metallurgy using high-energy ball milling showed gradual increase with the carbon nanotube concentration up to 1.5 wt.%. The mechanical properties will decrease for higher carbon nanotube concentrations [18].

2. Experimentation

The as received AA7075 alloy has the following percentage of alloying elements as mentioned in table 1.

Table 1: Chemical Composition of AA7075

Alloying elements	Percentage
Zinc	5.6- 6.1
Magnesium	2.1 - 2.5
Copper	1.2 - 1.6
Silicon, Iron, Manganese, Titanium, Chromium and other metals	< 0.5

The as received multi-walled carbon nanotubes are 99% pure. Specifications of the received carbon nanotubes were given in table2.

Table 2: Specifications of Carbon Nanotubes

Specifications	Description
Type	Multiwall
Purity	>99%
Average Diameter	10-18 nm
Average Length	10-20 μm
Amorphous Carbon	<1%
Surface Area	370 m^2/g
Strength	10-60 GPa

2.1. Fabrication of AA7075-MWCNT metal matrix composites

The specimens were fabricated by stir casting process as this process is the best method to achieve high strength to the specimens. The stir casting setup consists of an electric furnace, stirrer motor with stirrer, stirrer holding attachment and temperature indicating panel with thermocouples. The maximum range of temperature achieved in the furnace is 1200 ^{0}C with 250 kW high frequency Induction furnace and 5 kg capacity steel crucible. The melting temperature is maintained around 660 to 700 ^{0}C with speed of 350 to 400 rpm and vibration based high frequency stirrer was used for uniform mixing of reinforcing particles in the base metal. The required weight amount of aluminium alloy and CNT particles were found out by the calculations from the designed pattern volume. Aluminium 7075 alloy was taken in form of rods with diameter of 6mm, were broken into small pieces so as to accommodate them into the crucible. Electric furnace was used for the melting of the aluminium alloy. The melting point of the alloy is 650 and it was superheated by 100, so the temperature was set at 750 ^{0}C. CNT powder (0.5% by weight) was placed in another crucible and was preheated to temperature of 1000 ^{0}C in second furnace. The preheating was done in the presence of air so that it assist in removing surface impurities, desorption of gases and formation of oxide layer around each particle which will act as protective layer and inhibit the reaction between the CNT powder and molten aluminium alloy . The molten aluminium alloy was stirred continuously by using electric motorized stirrer running at 200 rpm, in the crucible. Due to the stirrer action there will be formation of vortex in the molten metal and this vortex produces a pressure difference along the depth and radius.

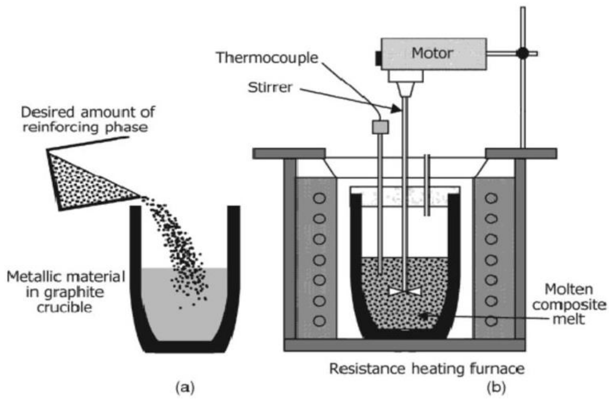

Fig. 1: (A) Mixing of CNT Powder in Molten Aluminium Metal. (B) Resistance Heating Furnance with Motorized Stirrer for Uniform Mixing of Reinforced CNT in Al Matrx.

The process of introducing CNT into the molten matrix was done in two consecutive steps with 0.25% by weight each time. This was done to get more uniform mixing and to reduce the formation of clusters of CNT into the molten matrix. The preheated CNT 0.25% by wt.in above mentioned percentage by weight were then added to the side of the vortex formed. The pressure difference induced by vortex, forces the CNT deep into the molten aluminium and across the radius of vortex. This phenomenon helps in uniform mixing of CNT into the molten matrix. The stirring was continued for 5 min while the temperature of the furnace was set at 900°C. After completion of the first mixing step, again 0.25% CNT (0.25% of initial AA7075) was added to the molten aluminium that already contains 0.25% CNT, to complete the final stage of mixing with overall 0.5% by weight CNT in molten metal and the specimen was removed after solidification. The above steps were repeated to obtain the remaining specimen with 1.0 wt%, 2.0 wt% and 5.0wt% of CNT respectively in AA7075.

3. Results and discussion

3.1. Micro-structure examination using SEM-EDX

Figure 2 shows the micro structure and chemical composition of fabricated specimens. The distribution of carbon nanotubes was found to be satisfactory and no agglomerations of carbon nanotubes were found in matrix. The white color marks indicated the traces of copper metal which was one of the alloying metals.

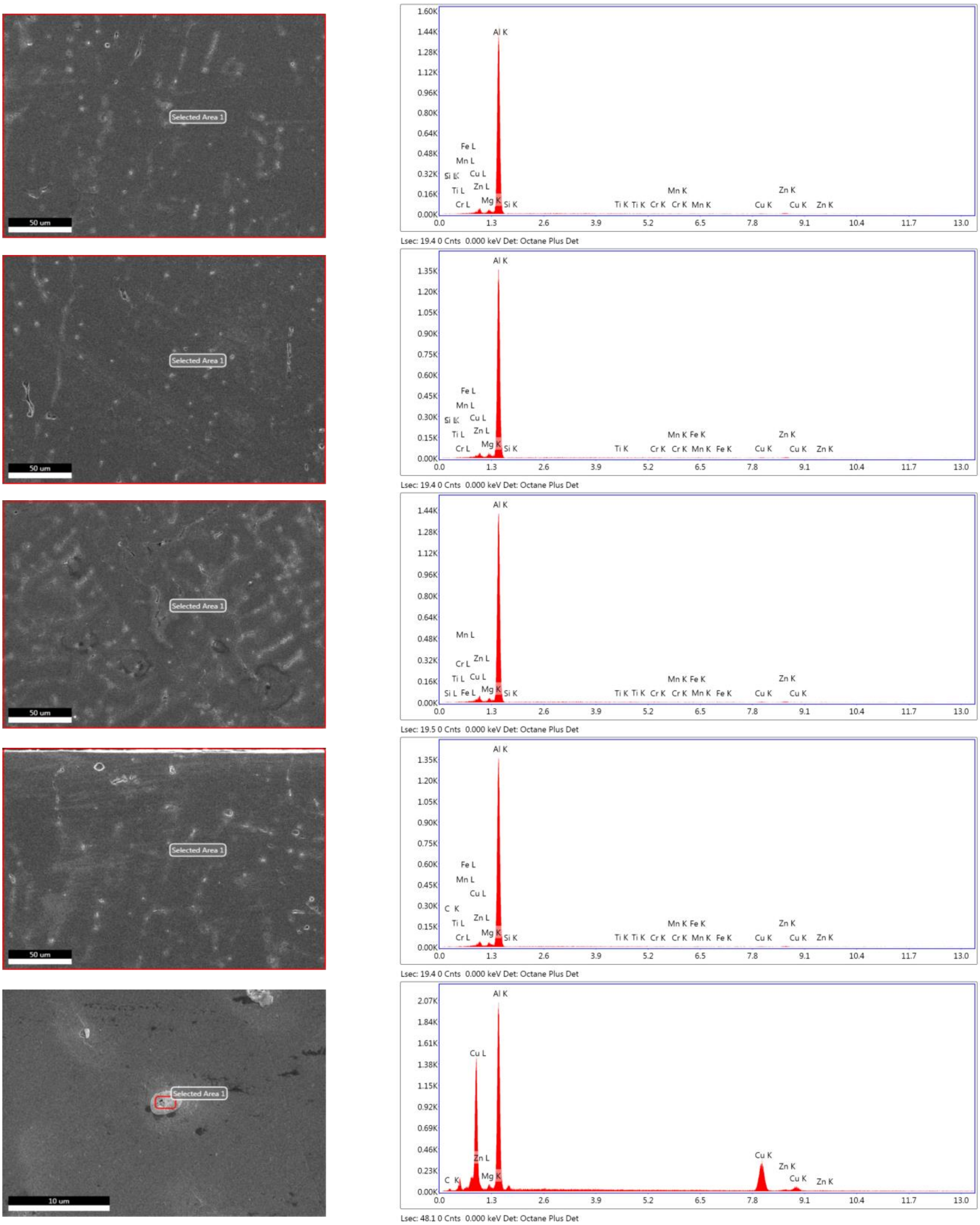

Fig. 2: Microstructure of the Fabricated Specimens (Top to Bottom: Pure AA7075, 0.5 Wt%, 1 Wt%, 2 Wt% And 5 Wt% of MWCNT in AA7075) with Elements Composition in the Selected Areas as Mentioned.

3.2. Impact strength

Impact strength is the capability of the material to withstand a suddenly applied load and is expressed in terms of energy. Charpy impact test was carried out in accordance with the ASTM E23 standards to investigate the impact strength of the specimens. The impact strength of the composite found to be increasing gradually with the increase in carbon nanotubes (MWCNTs) weight percentage (0.5wt%, 1wt%, 2wt%, 5wt %) in AA7075 matrix when compared to pure AA7075. The maximum of 90 % increment was found in AA7075- 5wt% CNT matrix.

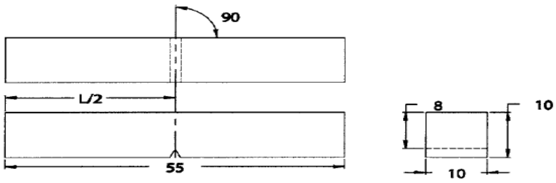

Fig. 3: Cross-Sectional Views of Specimen as Per ASTM E23 Standards for Impact Test.

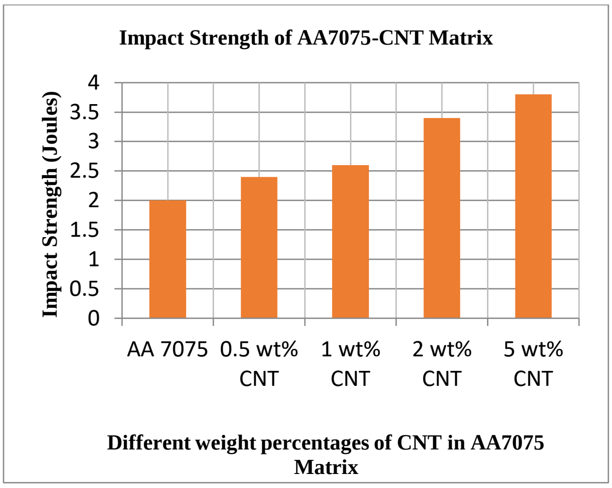

Fig. 4: Variation of Impact Strength of AA7075-CNT Matrix with Increase in Weight Percentage of MWCNT.

3.3. Flexural strength

Flexural strength, also known as modulus of rupture or bend strength is a material property defined as the stress in a material just before it yields in a flexure test. Three point bend test was carried out in accordance with ASTM D790 standards to determine the flexural strength. The Flexural strength of pure AA7075 was found to be 71.52 N/mm². The trend shows that flexural strength increases gradually with increase in carbon nanotubes (MWCNTs) weight percentage (0.5wt%, 1wt%, 2wt%, 5wt %) in AA7075 matrix. The maximum of 125 % increment was found in AA7075- 5wt% CNT matrix.

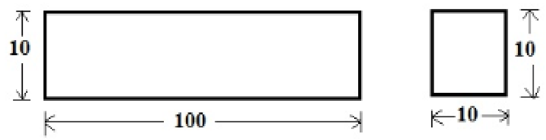

Fig. 5: Dimensions of the Specimen as Per ASTM D790 for Three-Point Bend Test.

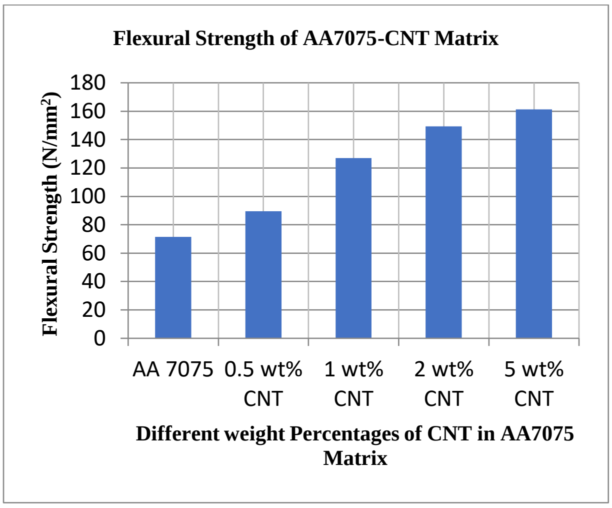

Fig. 6: Variation of Flexural Strength of AA7075-CNT Matrix with Increase in Weight Percentage of MWCNT.

4. Conclusion

The metal matrix nano-composites proved to be the best choice to replace the existing metals or alloys in the area of automobiles and aerospace due to their enhancement in the properties. The flexural strength and impact strength found to be increased up to a maximum of 125% and 90% compared to pure AA7075 for 5wt% of carbon nanotubes.

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