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Experimental Studies on Mechanical Properties of Carbon Nanotube Reinforced Aluminum 7075 Composite Material

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Highlights:

- Carbon nanotube reinforced aluminum composite was prepared by stir casting technique.
- Microstructure studies were carried out to analyze the reinforcement material and its distribution.
- The produced specimen was tested for tensile and compression strength as per the ASTM norms.
- Considerable improvement in tensile and compression strength were tabulated in the results.

Abstract. In the present work multiwalled carbon nanotubes were added as reinforcement to aluminum 7075 matrix at 0.5%, 0.75% and 1.25% by weight proportion through stir casting technique. The mechanical properties of the produced composite were studied. The composite has considerably good tensile and wear resistance properties and hence finds its best suited application in aircraft frame and wings structures. Microstructure analysis through SEM showed a uniform distribution of the reinforcement material in the matrix. XRD graphs were taken at selected points during microscopic studies to determine the chemical composition of the matrix alloy, the reinforcement and the composite. The experimental results showed that 1.25% reinforcement in the composite material exhibited a tensile strength of 560 N/mm^2 and a compression strength of 649.6 N/mm^2 as the highest among the compositions. Thus, the reinforcement addition at 1.25% improved the tensile and compression strength of the composite material.

Keywords: *aluminum 7075; carbon nanotubes; compression test; stir casting; tensile test.*

1 Introduction

Aluminum based composite materials have impressive mechanical properties that make them useful for engineering applications in various fields. Suitable material selection for the intended application based on the properties of the material is

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crucial. Two or more materials are bonded at the molecular level following the principles of metallurgy. According to the experimental observations of Raghavendra, *et al.*[1], the tribological behavior of aluminum 7075 reinforced in aluminum oxide under dry sliding condition is a function of transition load and speed. Generally, stir casting and powder metallurgy techniques are two major ways in which the hybrid properties of materials can be obtained. Aluminum is a light-weight material used in many engineering applications. In the work carried out by Savina, *et al.*[2], homogenization of carbon nanotubes in an aluminum matrix was investigated by using anionic surfactants. In the work by Bamane, *et al.* [3] the properties of base aluminum were enhanced using carbon nanotubes as reinforcement in the aluminum alloy. As per the available results from Ullas [4], Saravanan [5], Balachndar [6], and Omkar [7], the allotropic form of carbon in tubular form is a promising choice for mixing with aluminum alloys for the enhancement of mechanical properties.

Synthesis of carbon-nanotubes (CNT) and their use in the development of composite materials has gained much importance, because of their uniqueness in properties. It is evident from the experimental results of Mohithkumar [8], Babu [9], Suresh [10] and Sambathkumar [11], CNT is a hundred times stronger and five times less dense compared to conventional reinforcement materials such as silicon carbide and silicon dioxide powder.

As per the vibration casting carried out by Muhammad Sayuti, *et al.* [12], addition of copper into aluminum enhanced the mechanical properties to a considerable extent. The experimental results by Manihandan[13], Musa [14] and Pradeep [15] showed that an increase in CNT content improves the mechanical properties up to 2% by weight ratio. However uniform mixing of two or more materials is a challenging task. Researchers have focused on various processes to improve the homogeneity of the mixture. Esawi and Morsi conducted a ball milling experiment for 48 hours with a 10:1 ball to powder ratio. During the powder metallurgy route of preparing the functionally graded aluminium composites, it is observed that the uniform distribution of the particles is possible damage of powder particles is negligible due to planetary ball milling[17] Scanning electron microscope analysis has been done by Grace & Dimas [18], who observed CNT clustering in the aluminum matrix when tubular mixing was eliminated.

The main focus of the present work was to develop CNT reinforced AA7075 composite material by stir casting with varying weight ratio at 0.5%, 0.75% and 1.25%. Experiments were carried out to study the microstructure of the composite materials by scanning electron microscopy and mechanical properties by testing of tensile strength, compression strength, hardness and wear.

2 Materials and Methods

2.1 Matrix Material

The matrix used in the present work was aluminum 7075 alloy. It has superior properties such as wettability, corrosion resistance, mechanical properties and heat treatability, and has structural applications in airplane construction. The properties of the base matrix are given in the Table 1.

Table 1 Chemical composition of AA7075.

Elements	Al	Zn	Cu	Fe	Mn	Mg	Cr	Si	Ti
Amount (wt%)	Balance	5.5	1.6	0.5	0.3	2.5	0.15	0.4	0.2

2.2 Multiwall Carbon Nanotube Powder

The carbon nanotubes used in this process were produced by chemical vapor deposition with a purity of 97% and a density of 1.7 g/cm^3. The properties are given in Table 2. Though CNT can be obtained by flame synthesis and sol-gel methods, their densities and the extent of purity cannot be matched by the CVD process.

Table 2 Properties of multiwalled carbon nanotubes.

Properties	Unit	Values
Carbon purity	%	Above 95
Diameter	10^{-9}m	9.5
Length	µm	1.5
Surface area	m2/g	250-300
Bulk density	kg/m3	66

2.3 Composite Preparation

An AA7075 composite cast was obtained by stir casting technique. The setup consisted of an induction melting furnace, a graphite crucible, and a hardened steel stirrer as shown in Figure 1. The 3 phase crucible with a 3-KWh coil and a stirrer-motor attachment had a melting capacity of 3 kg at a time. The crucible was preheated to 80 °C to avoid thermal shock. Ingot plates of aluminum 7075 were placed on the furnace top cover for initial preheating up to 60 °C and then placed in a crucible. The billets started melting at 450°C and the complete mass turned into molten state at 600°C. The motorized stirrer was then slowly inserted into the furnace and the molten aluminum was constantly stirred at a speed of 250 rpm. After 2 minutes of stirring the reinforcement powder was inserted slowly into the molten alloy. The reinforcement powder was wrapped in small aluminum foil packets. This technique of introducing the CNT powder assists to keep down agglomeration and helps uniform dispersion of the reinforcement in the base matrix. A white calcium stearate powder was used as scum during the process in order to separate impurities such as oxides and hydrates. Degasification was done using perchloroethane (C_2Cl_6) tablets to eliminate blowhole defects in the cast. After filtering the slag floating on the surface, the molten pool was poured carefully into preheated mold boxes and allowed to cool for 1 hour, after which the cast was removed by separating the mold boxes mechanically as shown in Figure 2.

Figure 1 Molten pool of the composite in a crucible.

Figure 2 Casted rods after cooling.

3 Results & Discussions

3.1 XRD Analysis

X ray diffraction analysis is an analytical technique used for elemental analysis and chemical characterization of newly developed materials and composites. In the present work, the CNT reinforced with AA 7075 composites were tested by energy dispersive X-ray spectroscopy to analyze the composition of the alloy materials. Figure 3 shows the aluminum alloy material without CNT reinforcement. In Figures 4 and 5 the carbon content present has almost the same pattern while Figure 6 shows the maximum CNT content, i.e. reinforcement added at 1.25% by wt. It can be observed that the presence of carbon nanotubes can be visualized by observing them at higher amplitude than other combinations. The observations are represented in the graph shown below with the wavelength along the Y axis and the intensity of energy released along the X axis.

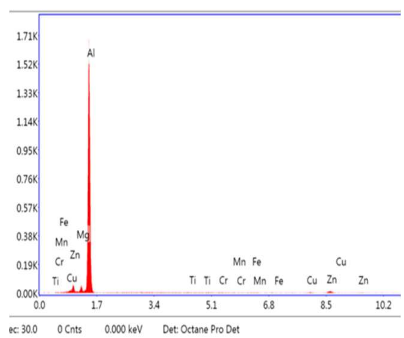

Figure 3 XRD image for AA 7075 alloy.

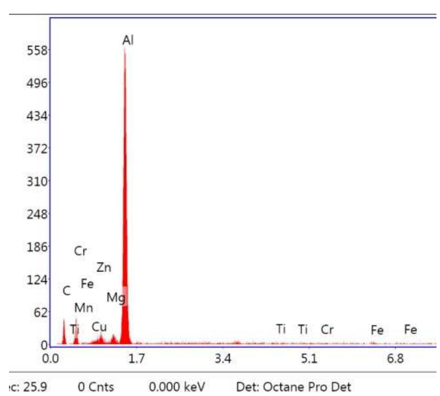

Figure 4 XRD image for AA 7075 alloy with 0.5% CNT.

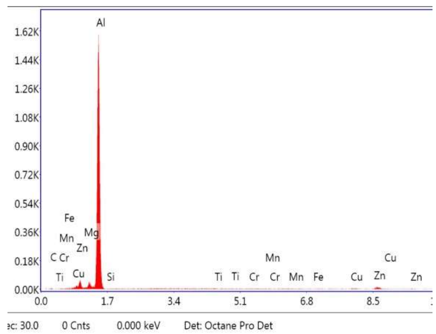

Figure 5 XRD image for AA7075 + 0.75% CNT.

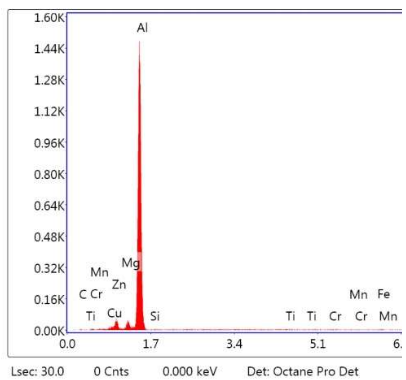

Figure 6 XRD image for AA7075 + 1.25% CNT.

3.2 Microstructure Studies

The composite prepared was analyzed under a scanning electron microscope to study its surface morphology at magnification ranging from 200 to 5 micrometer on a Vega 3 TeScan system. Some distinct CNTs were found in the 0.5 wt% samples that were trapped in an agglomeration, as can be seen in Figure 7, which may have a detrimental effect on the mechanical properties. A uniform distribution of the CNT reinforcements can be seen in Figures 8 and 9 wherein the agglomeration was very minimal and the CNT tubes were wrapped around each other and also around the base matrix material. Porosity among these samples was very small, as the reinforcement was added into the matrix wrapped in a thin sheet of aluminum. Hence, the method of introducing the reinforcement wrapped in packets helped to achieve cluster free binding with the base aluminum.

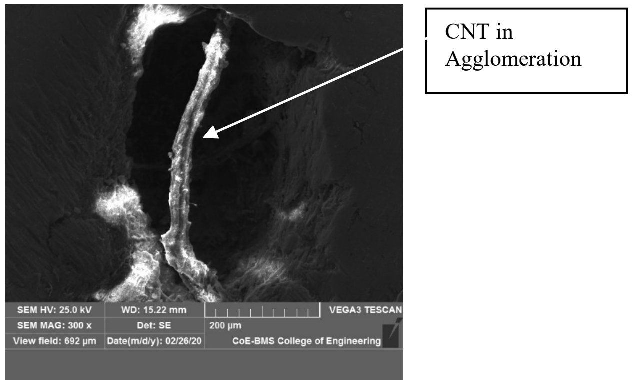

Figure 7 AA7075+0.5% CNT.

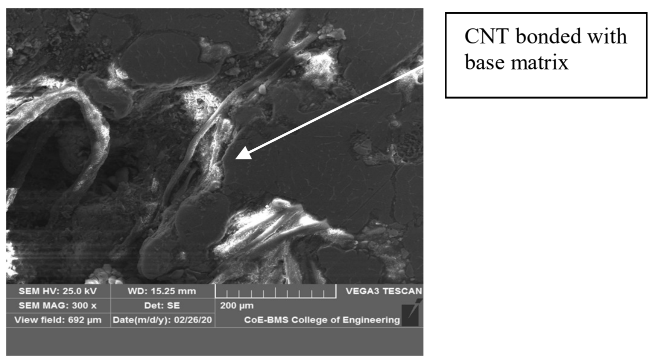

Figure 8 AA7075+0.75% CNT.

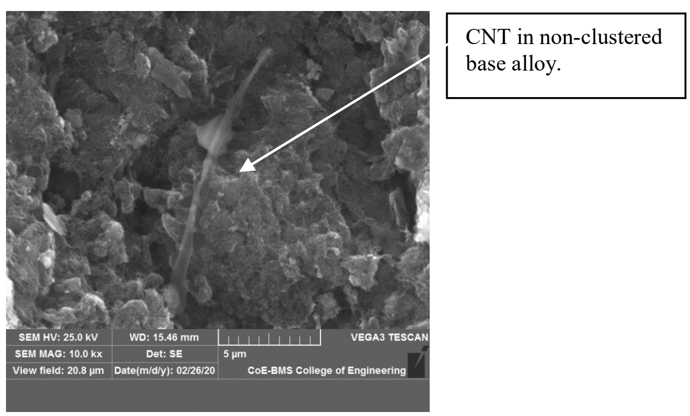

Figure 9 AA7075+1.25% CNT.

3.3 Tensile Test

The ingots obtained by casting were machined to get specimens for tensile testing according to the ASTM E8 standard, as shown in the Figure 10. The tensile test was carried out on three specimens for each percentage of CNT reinforcement in the AA7075 composite, as shown in Figure 11. The average values of the experimental results are tabulated in Table 3.

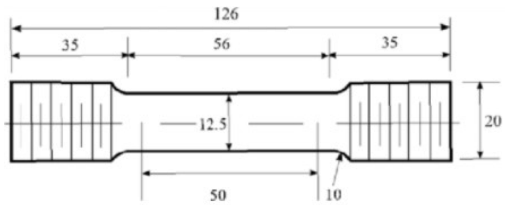

Figure 10 Specimen size for tensile testing per ASTM E8.

Figure 11 Specimen after machining for tensile test.

Table 3 Tensile test results.

Specimen	Gauge Length (mm)	C/s Area(mm^2)	Tensile Strength(N/mm^2)
	50.96	122.73	498
AA7075 alloy	50.80	121.10	490
	50.92	122.30	494
	51.58	124.54	512
AA7075+0.5%CNT	51.20	123.48	515
	51.30	124.30	513
	50.26	119.98	543
AA7075+0.75%CNT	50.04	121.56	544
	50.28	122.87	546
	51.49	121.54	560
AA7075+1.25%CNT	51.28	122.47	563
	51.56	124.30	567

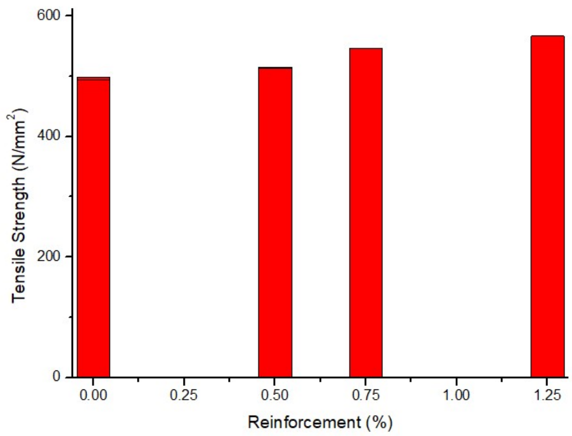

Figure 12 Tensile strength with reinforcement wt%.

3.4 Compression Test

A compression test was done according to the ASTM E9 standard, as shown in Figure 13. The specimens after machining are shown in Figure 14. During the experiment it was observed that the specimen without CNT content tended to yield fast, whereas the specimen with 1.25% CNT took more time until ultimate yielding. Three specimens of each percentage composition of reinforcement were prepared for testing and their average results are tabulated in Table 4.

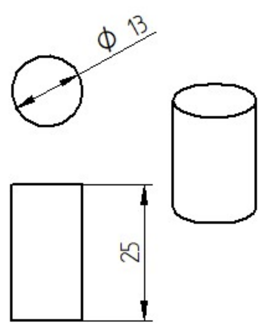

Figure 13 Specimen size for compression test per ASTM E9.

Figure 14 Compression test specimens.

Table 4 Compression test results.

Specimen	Diameter(mm)	C/s Area(mm^2)	Compression Strength(N/mm^2)
	13.10	134.79	431.56
AA7075 Alloy	13.12	135.19	432.46
	13.2	133.14	430.95
	13.17	135.61	428.87
AA7075+0.5%CNT	13.12	135.19	434.50
	13.16	136.03	438.75
	12.89	130.5	416.10
AA7075+0.75%CNT	13.10	134.79	418.5
	13.00	132.74	420.8
AA7075+1.25	13.03	133.35	550.4
%CNT	13.14	141.04	580.9

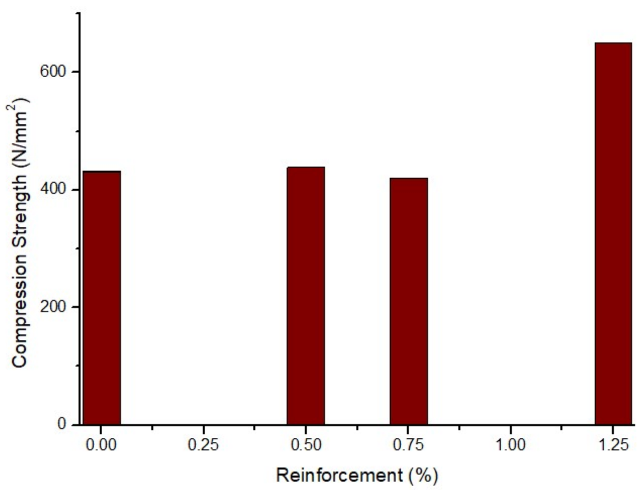

Figure 15 Compression strength with reinforcement wt%.

The maximum compression strength obtained in the test was 649 N/mm^2 for the 1.25% CNT in AA7075 composite. Beyond this value, testing still has to be done. It was observed in the experimentation that the higher the percentage of carbon nanotubes in the matrix material, the greater the compression strength of the composite.

4 Conclusion

Preheating the reinforcement powder, wrapping them in an aluminum foil and successively introducing these packets into the furnace helped to achieve uniform dispersion of the reinforcements. SEM images indicated uniform mixing of carbon nanotubes without cluster formation due to density differences. The experimental results showed that the porosity of the casting was reduced and a compression strength of 649.60 N/mm^2 was obtained with the 1.25% CNT in AA7075 composite. The results of the tensile test revealed that the influence of CNT addition tended towards an increase of the load bearing capacity. The maximum of 567 N/mm^2 obtained during the tensile test is an indication of the positive influence of the addition of CNT reinforcement to the base matrix, thereby supporting our objective of using CNT as an effective reinforcement of the aluminum matrix.

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