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FABRICATION AND MECHANICAL PROPERTIES OF ALUMINUM METAL MATRIX NANO COMPOSITE (AL6061/CNT)

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ABSTRACT

In this paper, Aluminum Metal Matrix Nano Composites (Al6061/CNT) are prepared using ultrasonic stir casting furnace by reinforcing different percentages of CNT 0.3%, 0.6% and 0.9% with the base material Aluminum Alloy 6061. The effects of different reinforcements on mechanical properties and internal structure of Aluminum Metal Matrix Nano Composites (AMMNCs) are studied. SEM Analysis of AMMNCs revealed the uniform distribution of Carbon Nano Tubes (CNT) in the Al6061 alloy. The considerable increase of Hardness and compressive strength at 0.3 wt.% and tensile strength at 0.6 wt.% are observed.

Keywords: metal matrix nanocomposites, Al6061, carbon nanotubes, ultrasonic stir casting, microstructure characterization, mechanical properties.

1. INTRODUCTION

To improve the ductility and fracture toughness of the conventional composites, the new class of materials known as Metal Matrix Nano composites (MMNCs) are developed by reinforcing particles of nanometer size in the base materials like Al, Mg, etc. The reinforcement of micro/ nano particles in the AMMC's has improved mechanical properties due to the reinforcement of high strength and high modulus particles like Nano sized CNT, Sic, Al_2O_3, B_4C, ZrO_2, Graphite, $FeTio_3$, etc. Aluminum Metal Matrix Nano Composites (AMMNCs) are widely used for high performance applications such as automotive, military, aerospace and electrical industries.

Typical applications for aluminum alloy 6061 include: Aircraft and aerospace components, Marine fittings, Transport, Bicycle frames, Camera lenses, Driveshafts, Electrical fittings and connectors, Brake components, Valves, Couplings.

Reinforcement Material used in this work is Multi wall Carbon Nano Tube (MWCNT) and the Production method is Chemical Vapor Deposition Method (CVD), Purity: >98wt%, OD: 4-6 nm, Length: <50nm and its applications of MWCNTs are a large number of present and evolving applications for MWNTs. These include: Electrically Conductive Polymers, Battery Cathodes, Improved Structural Composites, Water filtration membranes, other development applications include spray-coatable heater elements; thermal interface and other heat conduction materials; enhanced carbon fiber and others.

2. LITERATURE REVIEW

S. R. Bakshi [1] reviewed on carbon nanotube (CNT) metal matrix composites (MMCs). Cao. G, *et al*, [2]fabricated and investigated Mg–6Zn/1.5%SiC nanocompositesby ultrasonic cavitation-based dispersion of SiC nanoparticles in Mg–6Zn alloy melt. As compared to un-reinforced Mg–6Zn alloy matrix, the mechanical properties of the nanocomposites including the tensile strength and yield strength of the Mg–6Zn/1.5%SiC nanocomposites were significantly higher; the good ductility of Mg–6Zn alloy matrix was retained. Kobliska. J, *et al*, [3] Fabricated and investigated Mg-4Zn/1.5 pctSiC nanocomposites by ultrasonic cavitation–based dispersion of SiC nanoparticles in Mg-4Zn alloy melt. As compared to the Mg-4Zn magnesium alloy matrix, the tensile properties including tensile strength, yield strength, and ductility of the Mg-4Zn/1.5 pctSiC nanocomposites were improved significantly. Konishi. H, *et al*,[4] investigated on SiC nanoparticles reinforced magnesium and magnesium alloys including pure magnesium, and Mg-(2, 4) Al-1Si and Mg-4Zn were successfully fabricated by ultrasonic cavitation based dispersion of SiC nanoparticles in magnesium melt. The mechanical properties including tensile strength and yield strength were improved significantly while the ductility was retained or even improved when compared to un-reinforced magnesium alloy matrix. Harichandran. R, *et al,* [7] investigated the effect of the addition of micro- and nano-boron carbide particles to aluminum on the mechanical properties of the composites. The tensile test results showed that the properties of the samples containing up to 6% nano B4C-reinforced composites were better than the micro B4C-reinforced composites. The wear resistance of the nanocomposite significantly increased. Guoping Cao, *et al*, [5] Investigated on Mg/SiC nanocomposites were successfully fabricated by ultrasonic cavitation based dispersion of SiC nanoparticles in Mg melts. As compared to pure magnesium, the mechanical properties including tensile strength and yield strength of the Mg/SiC nanocomposites were improved significantly, while the good ductility of pure Mg was retained. Hai Su, et al, [6] Investigated on nano- Al_2O_3/2024 composites were prepared by solid–liquid mixed casting combined with ultrasonic treatment. Compared with the matrix, the ultimate tensile strength and yield strength of 1 wt.%nano-Al_2O_3/2024 composite were enhanced by 37% and 81%, respectively. Michael. F [9] summarizes the applications of CNTs like: bulk CNT powders are incorporated in diverse commercial products ranging from rechargeable batteries, automotive parts, and sporting goods to boat hulls and water filters. Kaushik. B.K [8] summarizes the electronic band structure of one-dimensional CNTs;

various transport properties, and their real-world applications. Manjunatha L.H [10] studies has highlighted the need for developing Al-CNT metal matrix composites. Microstructure images and SEM images of various compositions have been obtained. Poovazhagan. L, *et al,* [11] investigated Hybrid nanocomposites based on aluminum alloy 6061 reinforced with different hybrid ratios of SiC (0.5, 1.0 and 1.5 vol. %) and B_4C (fixed 0.5 vol. %). Rajesh. N, [12] summarizes on reviewing the processing of Nano composites and the effect of addition on different Nano reinforcements in aluminum alloy highlighting its merits and demerits. Effect of different reinforcements on AMMNCs on the mechanical properties like tensile strength, hardness, wear and fatigue is also studied in detail. Rajesh. N, *et al.,* [13] conducted turning experiments on Al6061 work material using HSS tool with and with out coolant at different cutting parameter values and Cutting Temperature, Surface Roughness are recorded for each experiment. After the literature review, Al6061 is taken as a base material and Carbon Nano Tubes (CNTs) is considered as best reinforcement material for the present work.

3. PREPARATION OF ALUMINUM METAL MATRIX NANO COMPOSITE (AMMNC)

In preparation of AMMNCs, ultrasonic stir casting method has been selected for the fabrication of AMMNCs. A crucible with a capacity of about 1kg was used for melting and ultrasonic processing. The ultrasonic processing system in Figure-1 is manufactured by Johnson Plastosonic. An ultrasonic probe made of Titanium alloy was used for ultrasonic processing. The ultrasonic probe was activated by a transducer fabricated from the piezoelectric transducer made by Aluminum offered the ability to convert high power electrical energy into mechanical motion. The transducer was activated with a fluctuating magnetic field. About 735gms of pure (99.9%) Aluminum was first melted in a mild steel crucible. When the temperature of the melt reached 700^0C, Nano CNT up to 6.7gms by weight was added into the Aluminum 6061 melt by preheating the powder for 1hrs upto (500^0C - 600^0C). The melt was stirred with a stirrer at about 800 to 1200 rpm for 10 to 15min to make the mixture homogeneous Al- Nano CNT melt. Then the ultrasonic probe, which is of 20mm in diameter and 135 mm in length was dipped into the melt and the melt was processed ultrasonically at a power level of 3.5 KW for about 10minutes. The processing frequency was 20 KHz. About 0.3%, 0.6% and 0.9% CNT Nano particles were slowly fed in to the Aluminum melt manually. The average size of the CNT particles was <50nm. The ultrasonic probe was dipped 20mm into the melt.

A K Type thermocouple with a steel protection tube was put in the melt to control the temperature of the melt. The melt temperature for ultrasonic processing was controlled at about 700^0C. After all the powder was fed into the Aluminum melt, the ultrasonic processing continued for another 15min. After ultrasonic processing, the ultrasonic probe was lifted, then the crucible was lifted to cast the Aluminum melt into a Steel permanent mold preheated to 500^0C with a resistance heater. The pouring temperature was 740^0C. The composition of Al6061 is tabulated in Table-1. and the weight in grams used for the fabrication of AMMNCs are tabulated in Table-2. In Table-3 shows about the process conditions used in the fabrication.

Table-1. Composition of Al6061.

Component	Mg	Si	Fe	Cu	Zn
Amount (wt.%)	0.8-1.2	0.4 – 0.8	Max. 0.7	0.15-0.40	Max. 0.25
Component	Ti	Mn	Cr	Others	Al
Amount (wt.%)	Max. 0.15	Max. 0.15	0.04-0.35	0.05	Balance

Table-2. Weight in grams used for the fabrication of AMMNC.

S. No.	Al6061	MWCNT	
	Weight in grams	Percentage	Weight in grams
1	700	0.0%	0
2	718	0.3 %	2.154
3	734	0.6 %	4.404
4	754	0.9 %	6.786

Figure-1. Ultrasonic fabrication setup.

Table-3. Process conditions.

S. No.	Description	Time	Temperature
1	Die pre heat	1 Hrs	500 ^{O}C
2	Nano CNT Powder Pre heat	1 Hrs	500-600 ^{O}C
3	Stirring speed	10 to 15 min	800 to 1200 rpm
4	Horn Timing	10 min to 15min	

4. TESTING OF AMMNC FOR ITS MECHANICAL PROPERTIES

The fabricated AMMNCs samples are tested for Tensile, Hardness and Compressive Strengths and the SEM tests, EDAX tests are conducted. To test the mechanical properties the fabricated material (100 mm X 100 mm) of is utilized as shown in Figure-2 as per ASTM E8 standards. The Mechanical Properties were tested and the results are tabulated in Table-4.

Table-4. Test results.

S. No.	Composition	Tensile Strength(MPa)	Compressive Strength (KN)	Hardness (BHN)
1	Al6061+0% CNT	98.18	76.42	33
2	Al6061+0.3% CNT	102.89	110.98	61
3	Al6061+0.6% CNT	111.73	86.18	45
4	Al6061+0.9% CNT	69.90	81.53	47

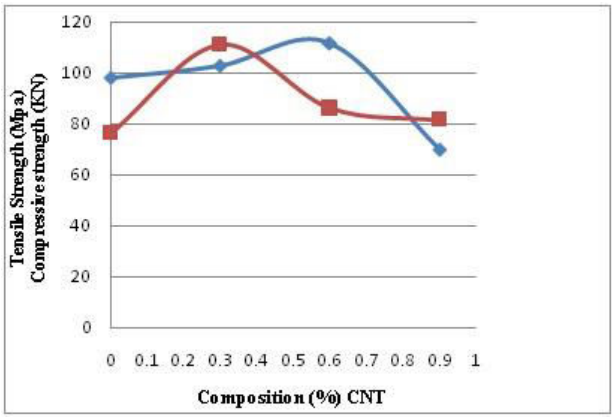

Figure-2. Composition Vs Tensile strength and compressive strength.

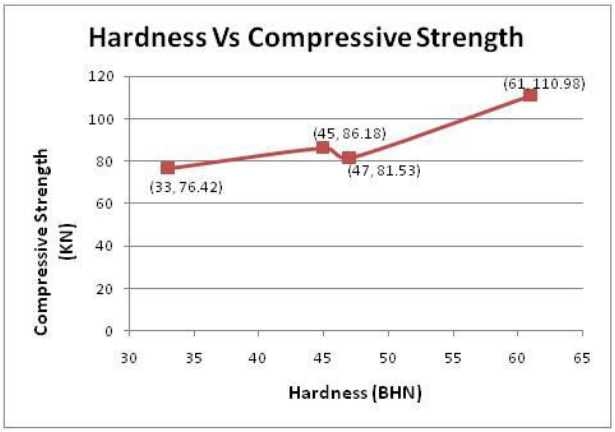

Figure-3. Hardness Vs Compressive strength.

As the percentage CNT in MMC increases the hardness also increases, this shows in Table-4, the graph is plotted between composition percentage versus tensile strength and compressive strength is shown in Figure-2, the peak hardness for conducted experiments is 61 (BHN) at 0.3% CNT. With respect to the hardness if the compressive strength is plotted on Y-Axis it shows a linear relationship except at 0.6% CNT due to bauschinger effect [13] which is shown in Figure-3 in clear. Due to the bauschinger effect an increase in tensile yield strength occurs at the expense of compressive yield strength due to that upon addition of CNT to MMC i.e., more than 0.3% with respect to the hardness, compressive strength falls down by deviating its original behavior, as shown in the Figure-3. Among the clusters of the fabricated AMMNC, covalent bond makes the material dense. As the percentage of CNT increases density also increases. From the obtained SEM tests in the resulted AMMNC the dispersion is well, giving good strength.

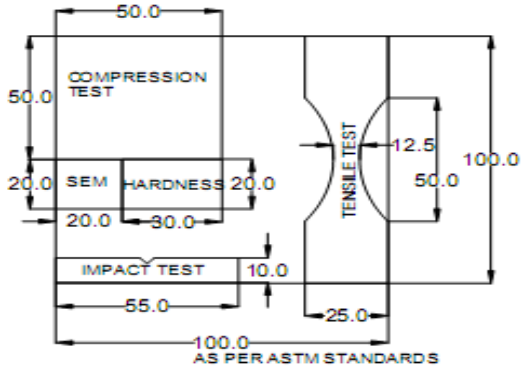

Figure-4. Material utilization chart.

A. Test for tensile strength

The composite is machined as dog bone shape and the tensile test is conducted for all the composites to determine the ultimate tensile strength, percentage elongation and yield stress were recorded for equal load intervals.

B. Test for compressive strength

Compression test was conducted for all the composites to determine the deformation, stress, and young's modulus from the stress-strain curve. Universal Testing Machine was used to compress the specimen and values of deformation were recorded for equal load intervals

C. Test for hardness

Brinell hardness tests were conducted to test the hardness of the material. A load of 100 kg-f was applied for about 10 sec followed by which indentation was measured under a microscope and the brinell hardness no. was calculated.

5. SEM ANALYSIS OF AMMNCs

The necessity to perform the SEM Analysis is to find out the dissipation of the reinforced particles (CNT Powder) with the base metal (Al 6061), uniformity and also EDAX test is used to find out the composition of the fabricated material. To perform SEM tests sample preparation is necessary. First the samples of all the specimens of different addition of reinforcements of the required size is cut and the surface is chosen and it is rubbed with different sizes of Emery papers. Then with the help of disc polishing machine and by pouring the Aluminum powder or paste with liquid (water) simultaneously and rotated the specimen on the disc polisher for about 15 - 20 revolutions, then etchant "Kellers Etch" (Distilled water -190 ml + Nitric Acid - 5ml + Hydrochloric acid - 3ml + Hydrofluoric Acid - 2ml) which is the best suited etchant for Aluminum and its alloys is applied on the specimen. The SEM Images Obtained for each specimen is shown in Figure-5 to Figure-7.

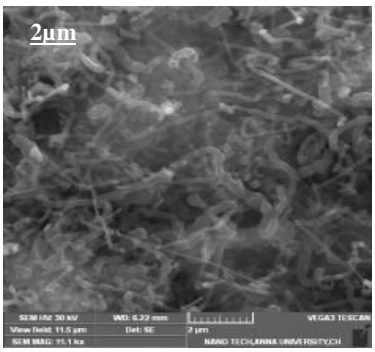

Figure-5. Al6061 + 0.3 % CNT.

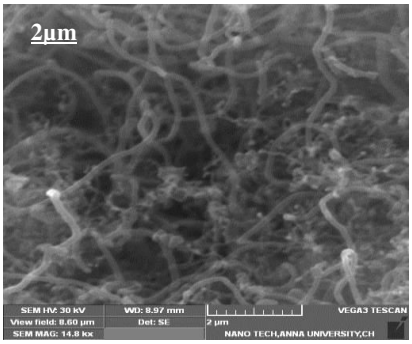

Figure-6. Al6061 + 0.6 % CNT.

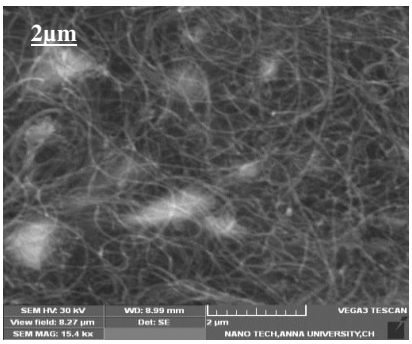

Figure-7. Al6061 + 0.9 % CNT.

From the Scanning Electron Microscope (SEM) Tests it is observed that the reason for increase in hardness with respect to the CNT percentage added to the base material is microstructure variations. As the atomic distance decreases between the Aluminum (Al), Carbon Nano Tubes (CNTs) the hardness increases. The same is observed when performed tests to know the mechanical properties as shown in the Figure-7, Table-4. The bonds between Al, C in resulted MMC are covalent in nature.

The EDAX report for the sample is shown in Figure-8.

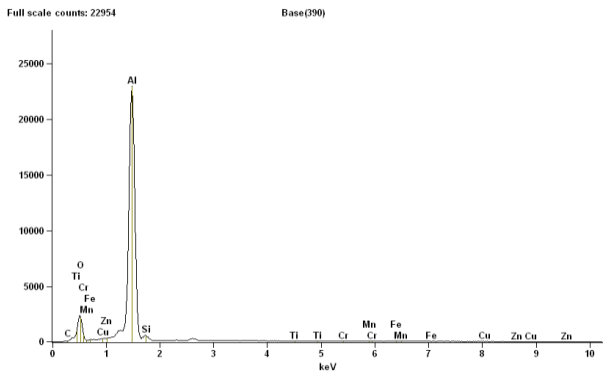

Figure-8. Compositional Analysis.

From the EDAX report itis concluded that there is presence of CNT in the base metal Al6061. Whereas in the general compositional analysis there is no carbon content present in the Al6061 alloy.

6. CONCLUSIONS

Aluminum Metal Matrix Nano Composite are fabricated by adding 0.3%, 0.6% and 0.9% percentage of Reinforced CNT to the base material Al6061 by using Ultrasonic stir casting process. The hardness and compressive strength are considered as a main criteria based on bauschinger effect. The maximum hardness & compressive strength is obtained for AMMNC at 0.3% CNT. If the tensile strength is considered as main criteria, the maximum tensile strength is obtained at 0.6 % CNT. The structure of AMMNC showed the uniform distribution of particles and good interfacial bonding of dispersed particles with Al6061 matrix alloy, which improves the hardness of the composites.

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