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Mechanical Properties and the Effect of Sliding Distance on Aluminium Composites Material Prepared Using Multiwalled Carbon Nanotubes as Reinforcements

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Abstract*: *Interest in multiwalled carbon nanotubes (MWCNTs) as the reinforcements for aluminium composites has gained much importance in the production of latest light weight and high specific strength materials. Various investigations have been conducted to understand the effect of the carbon nanotubes inclusion in the aluminium metal matrix. The present work was intended to enumerate the enhancement in the mechanical properties of the prepared aluminium composite material. The study involves the electroless technique of deposition of the nickel on the surface of the multiwalled carbon nanotubes in 35.58% proportion. Followed by the fabrication of the aluminium composite materials using stir casting technique. The determination of the tensile strength, hardness evaluation and wear studies relating to sliding distance were conducted in detail. The preparation of the composites were done with 0wt%, 2wt%, 4wt% and 6wt% of nickel coated MWCNTs addition, the composites were produced via liquid metallurgy routing. The increase in the strength when the specimen was subjected to the tension test was found upto 23.65% and the brinell hardness number was increased upto 15.38% when compared with ascast aluminium. The effect of variation of the sliding distance and wear mechanism of the fabricated composites were studied by keeping the load and sliding velocity as a constant factor and it was observed that the wear rates increased with the sliding distance. Wear behaviour results for the developed composites have been reported.

Keywords* : *Carbon nanotubes, Al7075 alloy, metal matrix composites, wear.

I. INTRODUCTION

This Aluminium is one of the highly demanded matrix material in the metal matrix composites category. since it is light weight and possess good tensile strength, fatigue strength, good machinability and it is also wear resistant. therefore automotive and aerospace industries are looking forward for better aluminium matrix composites to replace the high weight parts by low density aluminium alloy reinforced with carbon nanotubes composites, inturn which will enhance the efficiency and life. Silvain, J. F. et al. [1] investigated the kind of interfaces exhibiting in the Al carbon composites. The presence of nickel coating over the surface of the fiber reduced the formation of the carbide layer considerably that also served to enhance the mechanical properties Zhang, H.et al. [2] studied the influence of the length of the carbon reinforcements the main criteria was the understanding of the tribological context of the metal matrix composite in the presence of Titanium oxide and graphite nano particles. Rams J. et al. [3] studied the nano indentation properties of the AA6061 reinforced with the carbon the intermetallic bonding was considered for the study it was found that nickel coating present on the carbon fiber surface led to the homogeneity in the fibre distribution thereby increasing the composite properties. Hashim et al. [4] made an attempt to study the coating of the metal on the reinforcement surface which helped in preventing the reactions between the reinforcements and matrix making composites chemically inert but the creep resistance and stiffness were improved. Tamer ozben et al. [5] experimented on the composites of silicon carbide reinforcements with aluminum and analyzed the influence of reinforcements on machining parameters by varying, the feed, speed and depth of cut. It was seen that an increase in the rate of feed leads to the roughness of surface increase, therefore with the increase in the ratios of the reinforcements the roughness was decreased. Vijayaraghavan K et al.[6] utilized the stir casting technique to fabricate the composites of Al2024 reinforced with BC_4 and graphite the test results revealed that the hardness and tensile properties of the fabricated MMCs showed the increased values which met the confidence limits. S.Jeya Krishnan et al.[7] analyzed the distribution of Alumina(Al_2O_3- αphase) in Al6061 matrix. The observations showed that inclusion of Al_2O_3- α phase a nanoceramic powder as reinforcement has a prominent effect on the ultimate tensile strength (UTS), hardness and compression strength of the MMCs when compared with that of Al6061 matrix. The machinability of the composites could be controlled with the addition of the nanoclay. Sedat Ozdenet et al. [8] conducted the studies on the behavior of Silicon Carbide (SiC) particle for various temperature conditions for the impact load. Composites was affected by particles clusters, the cracks and very low interfacial bonding.

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The test temperature effects on the impact strength of all materials were not that much important. In the year 2008 Park et al. [9] conducted the high cycle fatigue (HCF) investigation of Al 6061-silicon-magnesium alloy the reinforcements was Alumina micro particles with different volume fraction. It was found that the fatigue strength of the powder metallurgy routing composites was greater than liquid metallurgy. M.B.Harun et al. [10] studied the behaviour of aluminium alloy metal matrix in 2006 by making use of varying amount of fly ash and Silicon Carbide. A microstructure study was done and it was found that an increment in the fly ash content leads to an increase in the porosity of the composites. Higher porosity level was observed when 15 wt% of fly ash was used. The hardness of the aluminium composites was increased with the mixture of Silicon Carbide. Ding et al. [11] investigated the behavior of the ascast Al 6061 alloy and carbon fiber reinforced Al 6061 MMCs. They found that the adding high-strength Al_2O_3 particulates in the Al 6061 results strengthen the microstructure of the 6061 aluminum alloy it is evident that the progress of the fracture phenomenon is interrupted at the region in front of the crack tip, probably due to a rise in the dislocation density this while measuring the strength of material causes a drop in its ductility. In 2012 D. Sujan et al. [12] studied the physical and the mechanical properties of aluminium matrix composites reinforced with Alumina(Al_2O_3) and Silicon Carbide(SiC). The composite were prepared by stir casting method. It was concluded that Al-SiC had higher hardness and tensile strength compared to other composites. The maximum tensile strength of composite obtained was 23.68% when 15 wt% of SiC was added. J.Udayprakash et al. [13] experimented on A413/flyash/Boron carbide hybrid composite and examined the effect of parameters like voltage gap, in time and off time pulse, The responses like metal removal rate and surface roughness was highly influenced by the voltage gap and feed of the wire. S. Kannan et al. [14] investigated the effect of machinability under the wet conditions and its effect on depth of cut. It was found that the depth of cut showed a reduction Nurettin Arslan et al. [15] investigated the residual stress components and yield points that are calculated for particular layer and compared with variety of reinforced layers. In the present study nickel coated MWCNTs were used as reinforcements and Al7075 was selected as the metal matrix the effect of tensile, hardness and wear for various wt% of MWCNTs was investigated.

II. EXPERIMENTAL PROCEDURES

A. Coating of multiwalled carbon nanotubes with nickel

The carbon nanotubes are prepared using chemical vapour deposition method. The multiwalled carbon nanotubes were cleaned in the beginning using distilled water for about 10 minutes to make it free from contaminants, so that the carbon nanotubes surface roughness will be retained. The MWCNTs are immersed on the hot vaccum oven and heated for about 200^0C, therefore the water on the surface is evaporated and carbon nanotubes are dried. This process makes the prepared carbon nanotubes free from impurities and debris the important chemical data of the MWCNTs are shown in table 1.

Table 1: Properties of multiwalled carbon nanotubes used

Property	values
Coefficient of thermal expansion (K)	3 x 10-6
Density (kg/m3)	2100
Nanotube Diameter (nm)	40
Nanotube length (µm)	50

The nickel coating on the MWCNTs is a electroless method and this process consists of three different levels such as Sensitization, Activation and Metallization level the mean thickness of nickel coating over MWCNTs was about around 2.213 µm. Figure 1. Shows the optical micrograph of the uncoated MWCNTs and the nickel coated MWCNTs the process parameters was controlled and the thickness of the nickel coating via electroless method was optimized by a statistical tool.

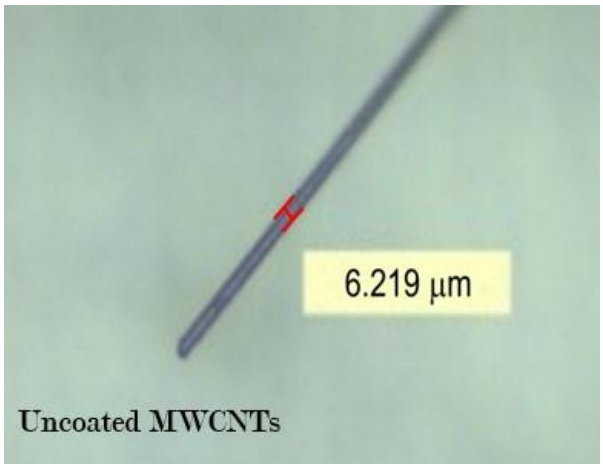


Figure 1(a): The optical micrograph of the uncoated coated MWCNTs

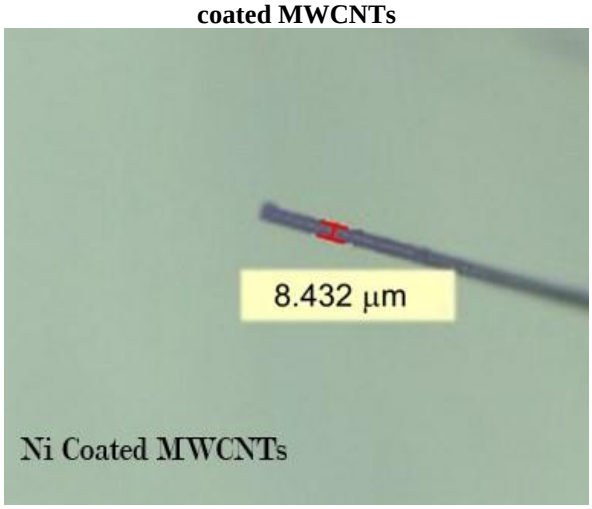


Figure 1(b): The optical micrograph of the uncoated MWCNTs

Table 2: Alloying composition of constituents of Al 7075 in percentages

Alloying elements	Percentage present (%)
Mg	3.7
Cu	0.3
Si	0.8
Cr	0.4
Zn	5.6
Mn	0.2
Zr	0.25
Ti	0.2
Al bal	88.55

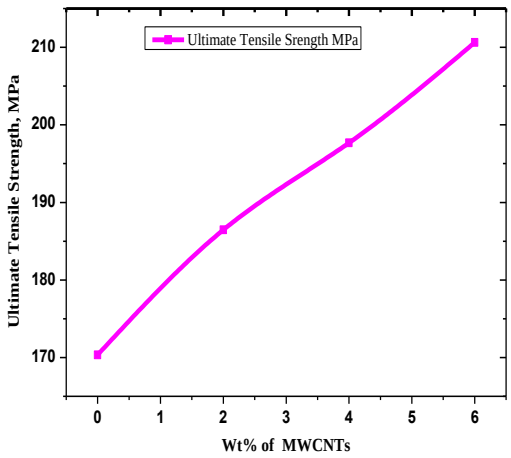
The resulting nickel coated multiwalled carbon nanotubes is intended to be used as a reinforcements with the aluminium matrix to produce composite materials. Al 7075 was selected as the matrix material since it possess excellent forming capabilities. Table 2 shows the elemental percentage of the constituents present in the Al 7075 alloy.From the thorough literature study, it was clear that there is insufficient work reported related to synthesis of aluminium based multiwalled carbon nanotubes (MWCNTs) reinforced metal matrix composites and examining the mechanical behaviour and studies on the wear of its composites.

B. Preparation of the composite material through casting technique:

The nickel coated multiwalled carbon nanotubes and the mould where the liquefied melt will be poured is placed in the bottom of the stir casting set up and heated for about 550° C. The carbon nanotubes are subjected to preheat using cups so that it helps to balance the temperature and avoids the temperature gradient which may damage the carbon nanotubes. The flux tablets of chloride salts say about 0.35% of the total weight of the Al 7075 was added into the furnace when aluminium begins to melt at around 650° C which acts as a degassing agent and removes the dissolved gases by the formation of aluminium chloride this foundry process will eliminate the porosity in the casting . The preheated MWCNTs are added into the crucible in required weight percents followed by the mechanical stirring to have homogeneous mixture. The stirring facilitates the matrix and reinforcements bonding by promoting its wettability, thorough stirring ensures the strong interfacial bonding between the matrix and the reinforcements. The stirring time also has the effect on the orientations and spreading of the MWCNTs in the Al 7075. Then the bottom opening will pour the liquefied melt directly to the mould and then it is cooled down to ambient temperature without any forcing agents. Then the specimens are separated out and subjected to machining to obtain the ASTM standard specimens to carryout various tests.

III. RESULTS AND DISCUSSIONS

The tension test was conducted and it was observed that ultimate strength under tension was increasing with the addition of the wt% of MWCNTs. It was found that with the variation in wt% of the carbon nanotubes from 0 to 2wt% there was increase in the ultimate tensile strength value of 9.45% from 2wt% to 4wt% the increase was 16.46% and for 6wt% strength value increment to 23.65%. This upward trend in the increase of the UTS values figure 3.1a was mainly due to the presence of carbon nanotubes the possible improvements in the strength was may be due to the uniform dispersion of the reinforcements in the matrix and this could have been achieved due to the better control of the stirring time and speed. The addition of the reinforcements caused the composites to loose its ductility as seen in figure 3.1(b) with the inclusion of more Wt% of MWCNTs the material incumbent towards brittle nature. From the figure 3.2a the SEM image of the fractured surface of the composites the ridges appearance indicates that irregular reinforcement breakdown may have occurred paving the way for strength enhancement and also in figure 3.2b the nanotubes pullout is observed which strengthens the idea that there was a uniform dispersion of the reinforcements. Through the hardness test, the observation made was that with the increase in weight percents of multiwalled nickel coated carbon nanotubes the hardness values will also increase. For the percentage reinforcement increase from 0wt% to 2wt% hardness increased by 9.58%, and 0wt% to 4wt% as and 0wt% to 6wt% of nickel coated carbon nanotubes has lead the increase in hardness by 12 and 15.38% respectively. The main reason for this increase in hardness may be due to the carbon nanotubes acting like a barrier to the dislocation movement. The possible increase could be due to the nickel coating of the carbon nanotubes that could have occupied the empty locations in the Al7075 lattice structure. The uniform dispersions of the reinforcements was observed creating the strong atomic force between the interface giving rise to strong matrix reinforcement bonding. Another possible reason could be the increasing with the dislocation densities as per Eshelby's model due to the gap between the co efficient of thermal expansion with respect to the matrix and reinforcements leading to the the large thermal mismatch occurs which may result in the blow of dislocations near the interface leading to the strain hardening effect since the surface area of the MWCNTs small leading to increased dislocation density according to Griffiths law.



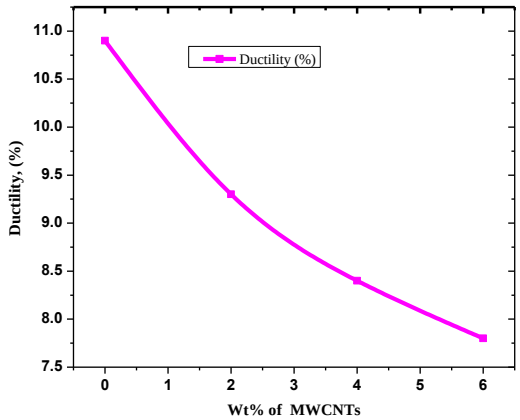
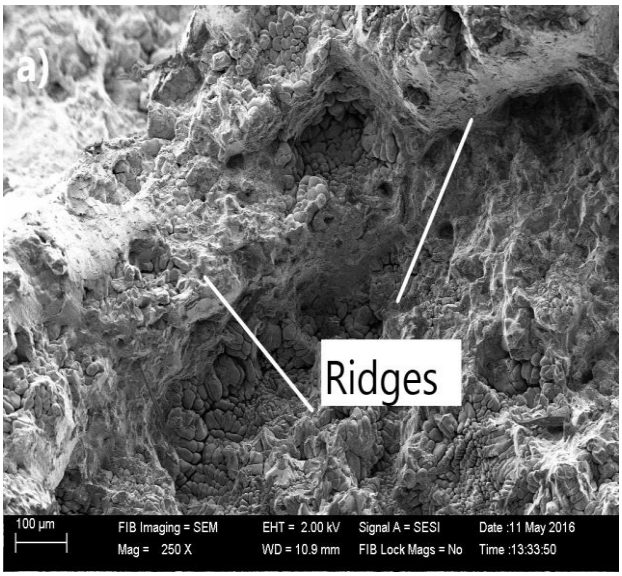


Figure. 3.1(a),(b): variation of ultimate tension strength and Ductility v/s wt% of MWCNTs



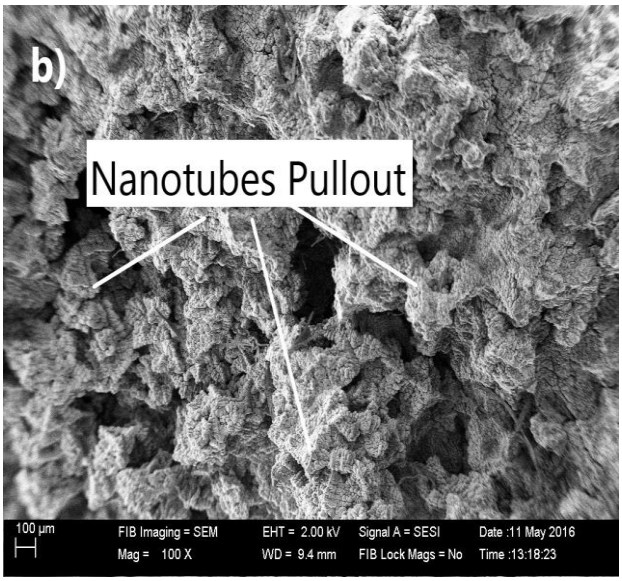


Figure. 3.2(a),(b): SEM images of the fractured surfaces of MWCNTs reinforced composites

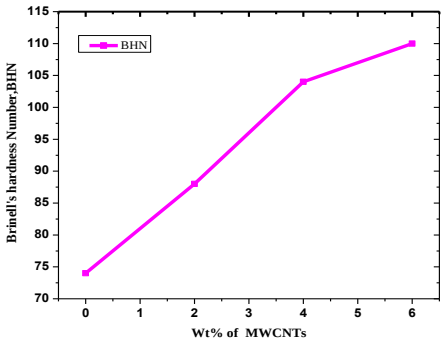


Figure. 3.2: variation of Brinell hardness number v/s wt % of nickel coated MWCNTs

The different sliding distance effect and the rate at which wear of the Al7075 nickel coated carbon nanotubes metal matrix composites occurs was studied. In this experiment the normal load and sliding velocity was kept constant, i.e. 10 N and 1.5 m/s. Figure 3.3 shows the manner in which the different sliding distance affects the wear patterns from the plot it is clear that as the sliding distance increases the wear promulgates faster initially upto 1km. later the rate of wear slows down till 1.8 km further increase in the sliding distances upto 2.0 km the wear increases considerably. In the sliding direction the wear debris could fill the grooves and with the localized raise in the temperature it may adhere to the composites thereby obstructing the wear. However the results depicts the decreasing trends with the increased wt% of MWCNTs as more no of nano particles would be available to close the grooves and therefore strengthens the composites.

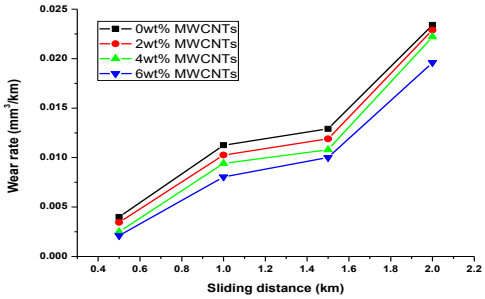


Figure. 3.3: wear rate vs. Different sliding distance of the specimen

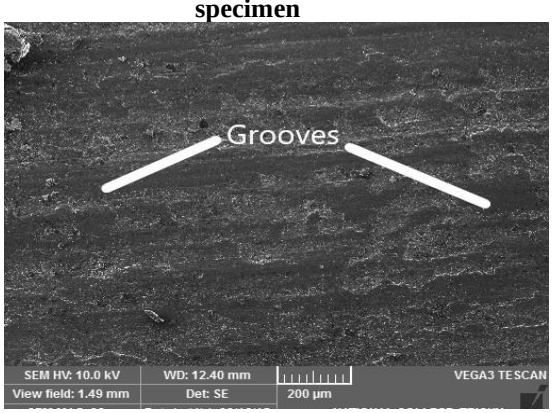


Figure. 3.4: SEM image showing the worn surfaces for the sliding direction of the specimen

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Figure 3.4 indicates that, the wear rate increases from distance 0.5 to 1km with greater rate and wear rate slows down from distance 1 to 1.5km. But again there is gradually increase in wear rate from 1.5 to 2km. In the graph, it can be observed that, as the wt% of the carbon nanotubes dispersion increases in the Al 7075 alloy, the rate of wear has been dropped down. For the better understanding of the wear mechanism of Al7075 alloy and its composites, SEM observation of the wear surfaces were done. In the figure it can be seen that the white layers on the worn surface of the composites indicate that the temperature at the surfaces is very high forming the grooves for higher sliding distances. Due to the increase in the dislocation densities according to Eshelby model the rate of wear of composite materials has been decreased but as the sliding distances increase the temperature along the sliding direction becomes more and this leads to severe plastic deformation at longer distances like 2km this increase in the temperature may also cause the adhesion of the composite to the pin causing the increase in rate of wear with the sliding distance increments.

IV. CONCLUSION

Electroless nickel deposition method for the MWCNTs proved to be suitable to obtain the required proportion of the coating thickness by controlling the process parameters. The mechanical properties of the Al 7075 nickel coated multiwalled carbon nanotubes for the different weight percents were evaluated. The ultimate strength under tension was increasing with the increase in Wt% of MWCNTs on the other hand the composite material lost its ductility of about 28.44% for 6wt% MWCNTs addition. the hardness increased by 9.58% for 2wt% and for 4wt% and 6wt% of nickel coated carbon nanotubes hardness increased by 12% and 15.38% respectively. Finally it can be concluded that as the density or Wt% of nickel coated MWCNTs in the Al 7075 matrix increases, the resistance to rate of wear of the composites gains the higher value compared to single monolithic material at the predefined constant load and sliding velocity acting on specimen.

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