Tribological Behavior of Multiwalled Carbon Nanotube Reinforced Aluminium Metal Matrix Composite.

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Abstract: Nanoscale reinforcements are the new trends with metal matrix composite to ensure better strength and low weight. In the current paper aluminium 7075 is used as matrix and multiwalled carbon nanotubes are used as reinforcements. Composite specimen is prepared through powder metallurgy technique with varied weight percentage of 0%, 0.5%, 0.75% and 1.25 % by weight. Microstructure studies are carried out to visualize the phase distribution of the reinforcement in the base alloy. Microstructure conducted evidences the Uniform distribution of reinforcement in an aluminium matrix. The experimental studies show that CNT reinforcement in the Aluminium alloy exhibits improved wear resistance. The wear coefficient of the specimen draws the attention towards performing the further studies to analyse the material behaviour at surface levels when a non-metallic reinforcement is used with a metallic alloy. Inserting beyond this range has no significant improvement in enhancement of wear resistance. The results obtained from abrasion wear test using pin on disc apparatus indicated the enhanced wear resistance and hence motivates to carry out further tests on wear morphology.

Keywords: Aluminum 7075, Carbon nanotubes, Powder metallurgy, Wear test.

1. Introduction

In the process of preparing Alumnium based composites, generally stir casting and powder metallurgy techniques are two major ways by which the hybrid properties of the materials can be obtained. Aluminum is the most promising and light weight material used in most of the engineering applications. Homogenization of the carbon nanotubes in aluminium matrix is investigated by using anionic surfactants. Aluminum based Composite materials are the promising ones with attractive properties that makes them useful in the field of engineering applications [1]. Suitable material selection for the intended application is the crucial task which depends on properties of the material. Two or more materials are bonded at molecular level with each following the principles of metallurgy. The tribological behavior of aluminum 7075 reinforced in aluminum oxide observed under dry sliding is the function of transition load and the speed [2].

The property of the base aluminum is enhanced using carbon nanotubes as reinforcement in the aluminum alloy and is highly depends on the type of reinforcements inserted in to the matrix [3]. As per the available literature the allotropic form of carbon in tubular form is the promising choice to mix with aluminum alloys for enhancement of mechanical properties [4-7].

Synthesis of Carbon-nanotubes (CNT) and their use in the development of composite material gained much importance, because of their uniqueness in properties. CNT has hundred times more strength and five times lower density compared to conventional reinforcement materials like SiC, SiO_2 [8-11]. As per the vibration casting carried out by Muhammad Sayuti et.al in [12], addition of copper into aluminium enhanced the mechanical properties to a considerable extent. Experimental results show that an increase in CNT content improves mechanical properties [13-15]. However uniform mixing of two or more materials is the challenging task. Researchers have focused on various processes to improve the homogeneity in the mixture. Esawi and Morsi conducted ball milling experiment for 48 hours with a 10:1 ball to powder ratio and not observed the damaged particle in the experiment [16, 17]. Scanning Electron Microscope analysis was done and found that CNT clustering is observed in the aluminium matrix when tubular mixing was eliminated. The main focus in this present work is to develop the CNT reinforced AA7075 composite materials by stir casting process for 0.5%, 0.75% and 1.25% weight ratio. Experiments were carried out to study the microstructure of composite materials using the Scanning Electron Microscope (SEM) and the wear resistance properties of prepared composite specimens.

2. Composite Preparation

2.1 Matrix used

The matrix used in the present study was AA 7075 alloy powder is shown in the figure 1. It has superior properties of wettability, corrosion resistance, mechanical properties and heat treatability. It has structural applications in the aeroplane building. Table 1 represents the percentage composition of alloying elements of the matrix material.

Fig.1 Aluminium 7075 Powder

Table 1. Percentage Composition of AA7075.

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

2.2 Reinforcement Used

Multiwalled Carbon nanotubes in the powder form as shown in the figure 2 are used as the reinforcement in the preparation of composite. They were obtained through chemical vapor deposition technique and with a purity of 97% and density of 1.7 g/cm^3. Important properties of the reinforcement material are given in the table 2.

Table 2. Properties of multi walled 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

Fig.2: Multiwalled carbon nanotube powder

2.4 Die used for compaction.

Die design is one of the most important steps in Powder Metallurgy process because the shape and attributes of the die will directly affect the final component. Alloy powders do not flow hydraulically because of the friction between particles and the dies. Hence the design, therefore should ensure adequate powder distribution within the die cavity to allow satisfactory compaction. The current die used in the work is made with A2 304 steel and is shown in the figure 3.

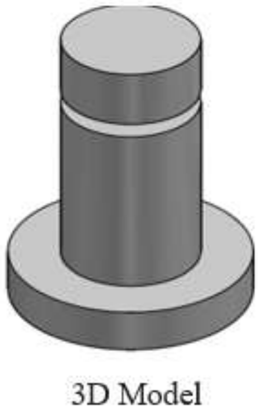

Fig.3: Part Structure of the die used for compaction

The dimensions of the die are derived from the specimen size used in the ASTM test procedures. The die parts are machined on CNC lathe and milling machine with a tolerance of 0.1 mm.

2.5 Ball milling and compaction

Ball milling is a process where the powders of base aluminium and CNT are blended by using revolving cup with a steel balls inside. The mixture is subjected to high energy collision from the hardened stainless steel balls. It uses the media in a rotating cylindrical chamber to mill materials into a fine powder. The powders of aluminium and CNT were blended with a varying percentage of 0.5%, 0.75% and 1.25% by weight along with aluminium powder without reinforcement. For each sample milling is done for one hour for proper mixing of both the powders. Thus the blended powder is transferred to the die unit carefully and then compacted in the hydraulic press machine for the load range of 80 to 100KN.

Fig.4: Hydraulic press

Fig.5: Green Compacts obtained

2.6 *Sintering*

Sintering is the process that allows the compacted powdered metal to bond. The part produced after sintering is close to the finished part. still contains between 5-15% porosity and is thus weaker than a finished product resulting in sub wrought steel properties.

The specimen is sintered in an organ filled furnace at a temperature of 450°C for 3 hours duration. After switching off the furnace it took additional one hour for the specimen to come back to atmospheric temperature. Once the specimen attains room temperature, it is taken out from the furnace and cleaned to remove surface oxides developed at a minor scale using soft brush. The sintered specimen are shown in the figure 6.

Fig.6: Specimen after sintering

3. Results & Discussions

3.2 Microstructure

The microstructure of the prepared composite is carried out on field emission scanning electron microscope (Fe-SEM). The dispersion of carbon nanotubes in the matrix can be verified with the help of images listed below. The specimens prepared for microstructure are shown in the figure 7. In the figure 8, CNT with the diameter 14 nm and 15.73nm can be observed. These samples possess better wettability with the aluminium powder of 200 micron size. Reinforcement beyond 1.25 % with the matrix will result in the agglomeration which affects the phase of distribution.

Fig.7: Specimen prepared for Fe-SEM test.

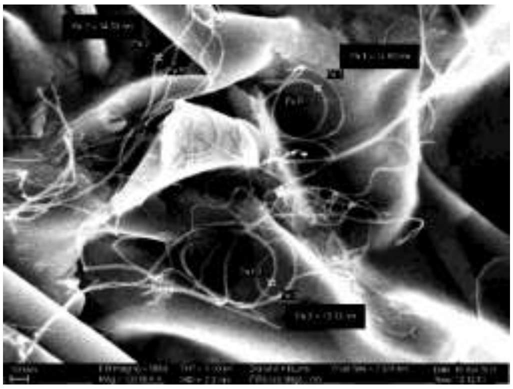

Fig.8. CNT at 100nm scale in 0.75% sample

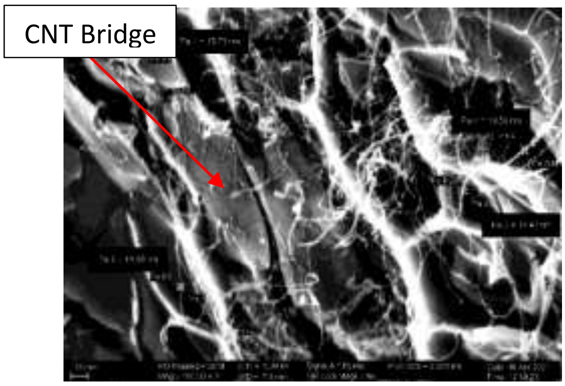

Fig.9. CNT bridge in 1.25% sample

The level of compaction actually depends on the duration of the ball milling and the types of the balls used for the purpose. Since in this work hardened steel balls of 5mm diameters are used, it is evident from the microstructure shown in the figure 9 that, the carbon nanotubes form the better bonding and they formed the bridge between intermolecular boundaries.

3.5 Wear Test

Pin on disc sliding wear test procedure is followed as per the ASTM G99 standard to investigate the tribological response of the current composite with Alumnium 7075 as the matrix and Multiwalled carbon nanotubes as the reinforcements. Wear test is done for 10N,20N and 30N load for all the four combinations of reinforcement with the varying sliding distances and speed. The values of coefficent of friction with respect to the time duration at 250, 300 and 400 rpm for all the four combinations of CNT are listed on the graph as shown in the figure 10 and 11 respectively.

Fig.10. A graph of friction coefficient v/s time at 250 rpm.

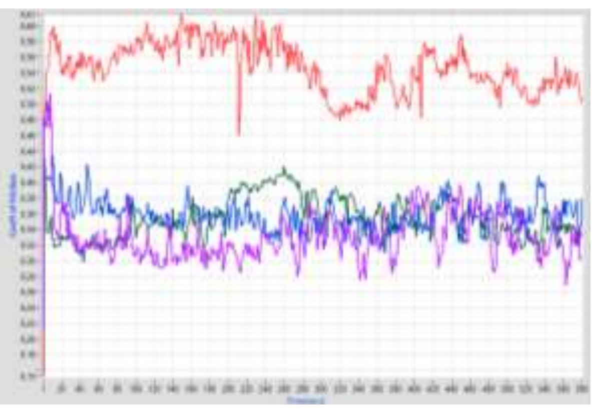

Fig.11. A graph of friction coefficient v/s time at 300 rpm

In the above figures, green line represents the specimen without CNT content and the Blue, Purple, and Red lines indicates the wear specimen with 0.5%, 0.75% and 1.25% CNT reinforced with them respectively. At a rotational speed of 250 rpm, it is observed that the aluminium powder without reinforcement has got a least frictional coefficient and the specimen with 1.25% CNT has maximum friction coefficient shown in red line. Whereas at 300rpm there is a considerable dip in the value in 0.5% and 0.75% of CNT specimens. It is the resulted due to increased content of CNT and hence brittleness increased which made these line to get overlapped each other.

4. CONCLUSION

The composite is prepared for different weight percentage of CNT having 0%, 0.5%, 0.75% and 1.25% by weight in powder metallurgy process. Microstructure by Fe-SEM procedure is performed to analyze the presence of reinforcements in the base aluminium powder. Ball milling process followed during the compaction ensures proper blending of both the powders. Since the time duration is of 1 hour in ball milling, it was possible to get proper bonding between the individual particles of both the powders. Since Aluminium 7075 is brittle due to the presence of magnesium in it, sintering in an organ filled furnace helped to maintain the strong bondage of both the powders. Form the worn surface morphology, it is evident that the abrasion wear is predominant in the regions where in the reinforcement content is less and more wear is observed at all those regions where the CNT content is minimal. Experimental results show that addition of CNT upto 1.25% resulted in an increased wear resistance. With the highest coefficient of friction being 0.83, CNT added to the aluminium matrix possess a better property for tribological behavior.

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