ISSN 2229-5518

Fabrication, Microstructure, Hardness and Wear properties of Extruded MWCNT- Reinforced with 6061Al Metal Matrix Composites

Manjunatha L.H.[1] P.Dinesh [2]

1.Department of Mechanical Engineering, Reva Institute of Technology,Bangalore,

2.Department of Mechanical Engineering ,MSRIT,Bangalore.

Abstract

MMC's are popular in engineering applications because of low density and high stiffness. Carbon Nano tube of late, has emerged to be an excellent reinforcement material for Al6061alloy based metal matrix composites. In the present experimental investigation, Al6061alloy as matrix material and up to 0.5 wt% of multi-walled carbon nano tube particulate composite was fabricated using the liquid metallurgy route. The wear and friction characteristics of the composite in the extruded conditions were studied by conducting sliding wear test. The sliding wear behavior of the MMCs were investigated by varying parameters like normal load, percentage multi-walled carbon nanotubes. Pin-on-disc wear testing machine was used for investigating sliding wear behavior. The worn surfaces were analyzed using optical microscope and scanning electron microscope. The results indicate that the wear resistance of the MWCNT reinforced material increased with increase in MWCNT content, but decreases with increase in normal load, and track velocity. The microscopic examination of the worn surfaces, wear debris and subsurface shows that the base alloy wears primarily because of micro cutting.Hardness study revals that as MWCNT content increases the hardnes value also increases significantly. Wear study results for Extruded specimens have been discussed.

Key words: microstructure, metal matrix composite, Carbon Nano Tube, Al6061 alloy, wear.

Correspondent author:Manjunatha L.H.

Email:lhmanju@gmail.com

1. Introduction

Al 6061 alloy is used in the transportation, construction and engineering industries. It has excellent mechanical properties in addition to good corrosion resistance due to which the alloy finds extensive application in naval vessels manufacturing.Al6061alloy metal matrix composites with carbon nanotube reinforcement can be a solution for such applications. It can satisfy the requirement of light weight with very good strength. Al6061-MWCNTcomposite is a metal matrix composite (MMC) that can be manufactured using the stir casting. With MWCNT as the particulate addition the properties of Al 6061 alloy can be greatly improved. The samples with various compositions produced will be evaluated for their microstructure,wear properties so that the best composition can be recommended for obtaining composites to suit various engineering applications.

In the following paragraphs the state of research in the area of present study is presented. According to [1,2,3] there are two main types of carbon nanotubes that can have high structural perfection. Single walled nanotubes consist single graphite sheets seamless rapped in the cylindrical tubes.CNT have electrical conductivity, thermal conductivity and mechanical strength that conventional materials cannot match. Nanotubes can be used in wide ranges in the field including chemical, electrical, mechanical and other applications. r young's modulus is 800Gpa and yield strength is 20Gpa . According to [4] the electrical properties of carbon naotubes are influenced by small structural variations. [5] have investigated the electronic properties of carbon nanotubes. Zhezhang et.al., [6] have conducted scanning tunneling microscopy to investigate the structure and electronic properties of carbon nanotubes produced from a discharge between graphite electrodes. Toru Kuzumaki's et.al., [7] has conducted research on mechanical behavior of carbon nanotubes/C60 composites . According to Eric W.Wong [8] the Young's modulus, strength and toughness of nanostructures are very important for various engineering applications, their investigations are based on atomic force microscopy to determine the mechanical properties of individual structural isolated silicon carbide nanorods and multi walled nano carbon tubes. The MWCNT are two times stiffer compare to silicon carbon nanorods. R.Byron Pipes et.al. [9] has investigated mechanical properties of helical carbon nanotubes arrays they have proposed two models for the prediction of effective elastic properties of helical array of CNT .Jean-paul salvetat –Delmotte et.al., [10] has come to conclusion based on his research that the CNT's have great potential has reinforcing elements for composites ,but they have identified two serious steps has the challenges in this directions.M.M.J.Treacy et. Al., [11] has found that CNT's have investigating mechanical properties in particular high stiffness and axial strength as a result of their seamless cylindrical graphitic structure.Their experiments are revealed that the average youngs modulus is 1.8Tpa.According K.T.Kashyap et.al. [12] CNT's are the ultimate carbon fibers because of their high young's modulus in the range of 1Tpa which is very useful for load transfer in nanocomposities. L.Sridhar et.al. [13] have investigated the characteristics of MWCNT's reinforced with aluminium matrix composites. The tensile yield and ultimate strength of aluminium MWCNT's increases to 90% with 2 wt% addition of MWCNT's. T.Laha et.al., [14] has propsed that CNT's have remarkable mechanical, electrical and thermal properties. Deepak Srivatsava and Chenyu Wei et.al., [15] have investigated on nanomechanics of carbon nanotubes and composites.

SWCNT's have young's modulus slightly larger than 1TPa and tubes can withstand about 5 to 10% axial strength before yielding which corresponding to stress of about 50Gpa before nanotube yield.Chunfeng Deng et.al.,[16]has found that carbon nanotube offers a kind of nanosize reinforcement that is light weight, a hollow core, has immense aspect ratio and has remarkable mechanical electrical and thermal properties. The investigators have used 2024Al matrix composites reinforced with 1 wt%CNT's which was fabricated by cold isotactic pressing followed by hot extrusion techniques. C.Srinivasan et. Al., [17] have investigated several methods available for production of CNT. Each method has it's strength and weakneses. Yanchen et.al.,[18] have used plasma assisted chemical vapour deposition method for producing well aligned graphitic nano fibers.According to C.F.Deng et.al.,[19] the demand for high performance damping materials is rapidly and continuously growing in a variety of aerospace, mechanical and civil systems. A.M.K.Esawi et.al., [20] has used powder metallurgy for fabrication of CNT's reinforced MMC's. In the present experimental investigation, the wear and friction characteristics of the composite in the extruded conditions were studied by conducting sliding wear test.The samples with various compositions produced will be evaluated for their microstructure,wear properties so that the best composition can be recommended for obtaining composites to suit various engineering applications.

2.Materials and Experimental Details:

2.1 Matrix material : Aluminium alloy 6061 is one of the most extensively used of the 6000 series aluminium alloys.

Table 1

Typical composition of Aluminum alloy 6061

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

Table. 2

Properties Al6061 alloy

Young's modulus	Shear modulus	Bulk modulus	Poisson ratio
70 GPa	26 GPa	76 GPa	0.35

2.2Reinforcement material: Carbon nanotubes are the strongest and stiffest materials Multi-walled Carbon nano tubes were procured from nano shell(USA) .

Table.3

Properties : Comparison of mechanical properties

Material	Young's modulus (TPa)	Tensile Strength (GPa)	Elongation at break (%)
MWCNT	0.2–0.8–0.95	11–63–150	15.4
Stainless steel	0.186–0.214	0.38–1.55	15–50

2.3 Fabrication of MMC by stir casting method: In the present study Al6061alloy-Carbon nanotube composite is prepared by stir casting technique. The various proportions of Carbon Nanotubes like 0, 0.1wt%, 0.2wt%, 0.3%,0.4% & 0.5wt% volumes are tried and castings are prepared. Al6061alloy is melted in the furnace to a temperature of 720^0C & then Carbon Nanotubes(MWCNT) which is in the powdered form(1nm) is poured slowly, simultaneously stirrer is made to rotate at an optimum speed of 450 rpm for a period of 5-10 minutes, then the melt is degassed by passing Nitrogen gas. Finally, the molten metal is poured into the finger metal mould. The mould is coated with chalk powder to prevent sticking of the molten metal into the surface of the mould. The cast samples are then subjected to heat treatment and hot extrusion. The solidified metal is removed from the die & is subjected to heat treatment where solutionizing is done at 590^0C for a period of 10 hours and then it is immersed in hot water maintained at 100^0C and allowed it to cool for 12 hours. And finally ageing is done at 175^0C for a period of 5 hours, then the samples for wear test is prepared according to ASTM standards. Ascast metal is removed from die and is subjected to hot extrusion where the specimen is heated for 590^0 C for about 1 hour and then it is subjected to hot extrusion. The extruded samples are prepared for wear test according to ASTM standards. The results were tabulated and the conclusions will be made based on the results. In the present work for the Extruded Al6061alloy-CNT MMc's specimen tests were conducted to evaluate the properties.

3.0 Results and Discussions:

3.1 Microstructure test : The optical microphotography of Al6061alloy and Carbon Nano Tubes composites are as shown in the Fig. 1 (a) to (d)

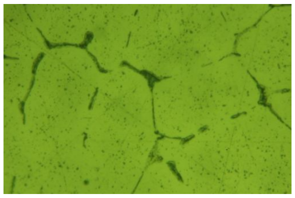

Fig.1(a)Al 6061 Alloy

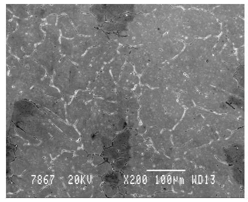

Fig.1(b)Al6061 Alloy

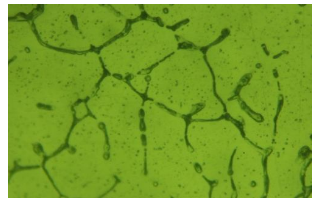

Fig.1(c)Al6061-0.1wt% CNT

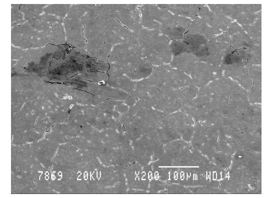

Fig.1(d)Al6061-0.1 wt% CNT

Fig.1(a) to (d) shows the Scanning Electron Micrographs and it is clearly indicates the homogeneity in the distribution of Carbon Nano Tubes particulates through the matrix alloy. The microstructure of the carbon nano tubes reinforced composite showed a reasonably uniform distribution of particles and good interracial bonding of dispersed particles with al6061 matrix alloy.There is a good interfacial bonding between Al6061alloy and carbon nanotube metal matrix which improves the hardness of the composites and also the wear behavior of the composites.

3.2 Hardness Test:

The Brinell hardness test method consists of indenting the test material with a 4 mm diameter hardened steel or carbide ball subjected to a load of 500 kg. The full load is normally applied for 10 to 15 seconds for at least 30 seconds. The diameter of the indentation left in the test material is measured with a low powered microscope. The Brinell harness number is calculated by dividing the load applied by the surface area of the indentation. The Extruded specimens were subjected to Brinell Hardness Test and the BHN are tabulated in below Table .4

Table.4

Effect hardness on Extruded specimens

Wt % of CNT	Hardness (BHN)
Reinforcement	Extruded
Al6061	32.08
Al6061-0.1 Wt%CNT	35.26
Al6061-0.2 Wt%CNT	38.56
Al6061-0.3 Wt%CNT	42.95
Al6061-0.4 Wt%CNT	39.02
Al6061-0.5 Wt%CNT	45.75

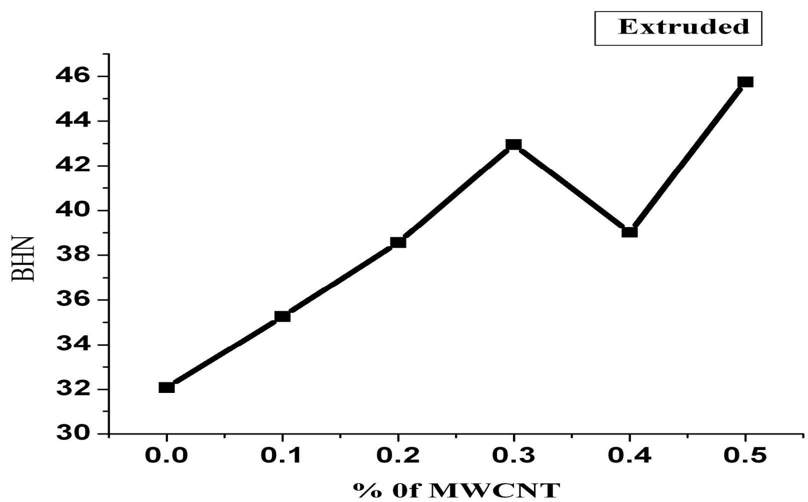

Fig.2 shows the graphical representation of the hardness(BHN) v/s Wt % of CNT

Fig.2 shows the graphical representation of the hardness(BHN) v/s Wt % of MWCNT in Extruded samples. In this observation of graph it is noticed that, there is an increase in the hardness in Extruded specimen.

3.3. Wear Test

A typical pin is cylindrical in shape with diameter equal to 8mm and length equal to 25mm. A typical disc has diameter of 180 mm and thickness of 12mm. The disc is ground to get a surface roughness of 0.8 micrometer. The disc is made of highly polished EN-25 steel with surface hardened to about 60 RHN.During wear testing height loss experienced by the pin specimen is measured in microns. Measurement of wear height loss of the pin was used to evaluate the wear loss during the wear test.

3.3.1 Effect of Sliding Time on Wear Loss on Al6061alloy- With weight% CNT MMCs for Extruded Materials:

Table. 7

Effect of Sliding Time on Wear Loss

Wt % of CNT	Wear loss in (microns) for various loads		
	10 N	20 N	30 N
Al6061	243.67	338.16	519.95
Al6061-0.1 Wt% CNT	192.04	312.10	430.61
Al6061-0.2 Wt% CNT	177.71	311.59	369.13
Al6061-0.3 Wt% CNT	156.19	270.01	354.82
Al6061-0.4 Wt% CNT	130.79	257.67	350.15
Al6061-0.5 Wt% CNT	127.15	212.72	320.14

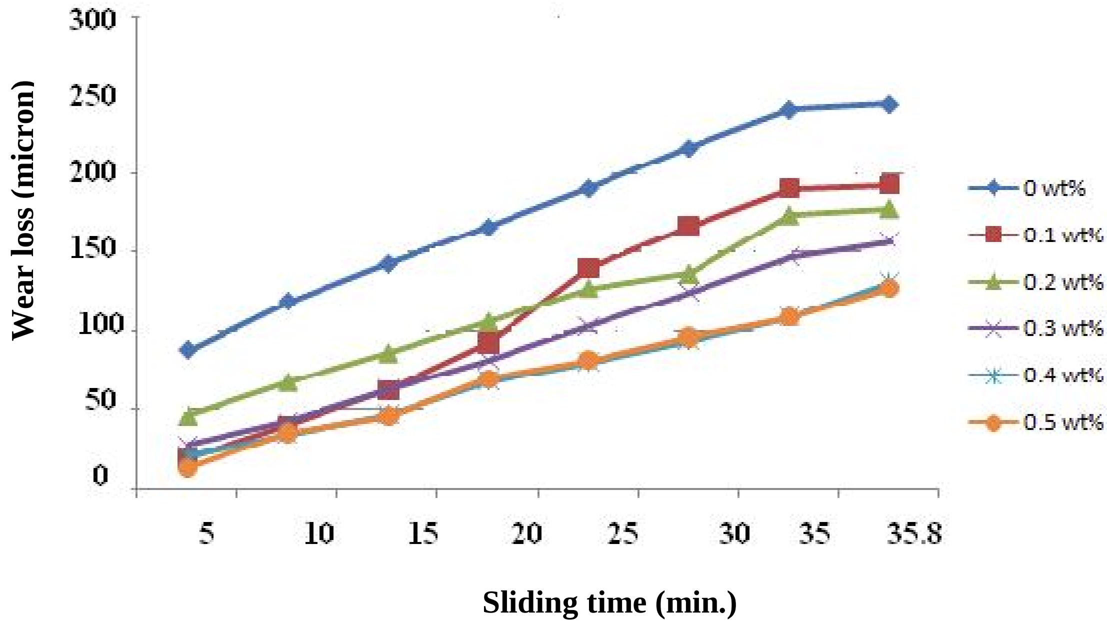

Fig.3(a). Wear loss of MMCs with Sliding Time at 10 N load for Extruded MMCs

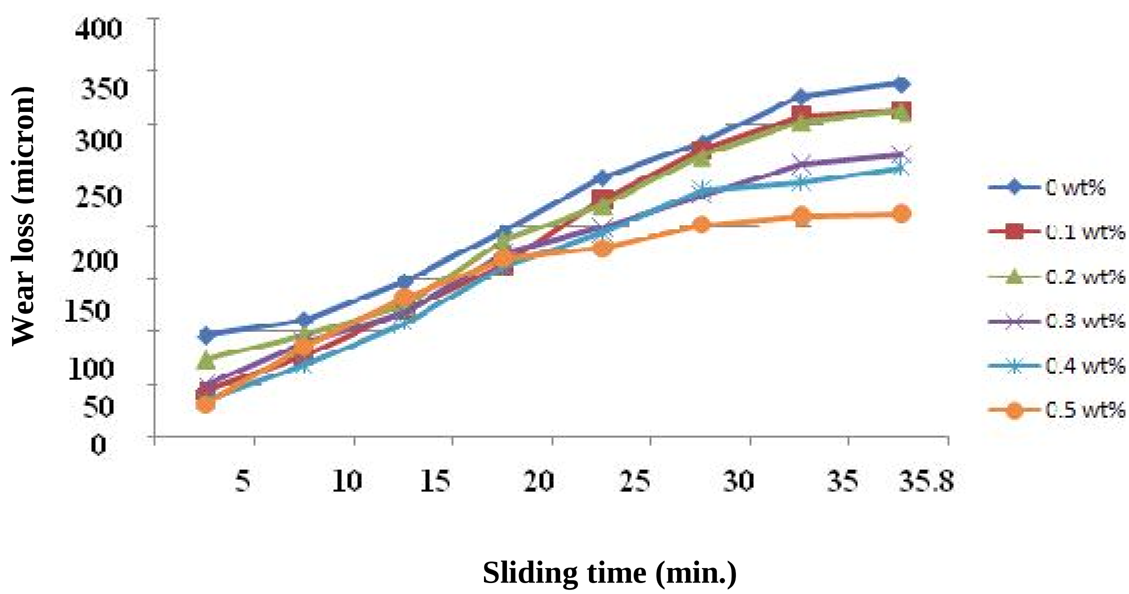

Fig.3(b). Wear loss of MMCs with Sliding Time at 20 N load for Extruded MMCs

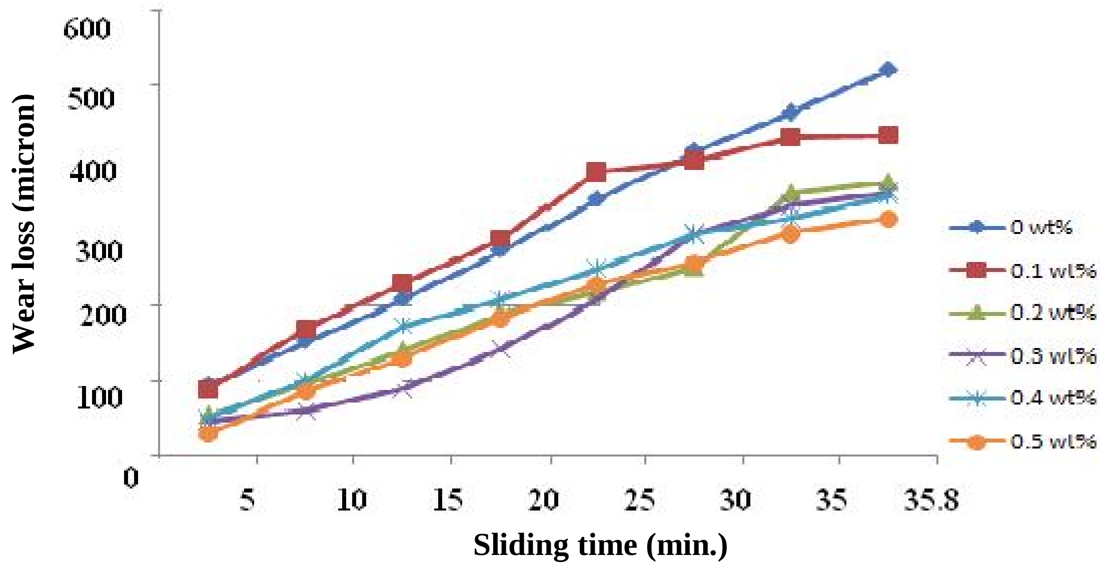

Fig.3(c). Wear loss of MMCs with Sliding Time at 30 N load for Extruded MMCs

The variation of wear loss with sliding time is as shown in fig.5 (a) to (c). With increase in sliding distance, there is higher wear loss for the matrix and the composites. At larger sliding distance, higher rise of temperature of sliding surfaces are unavoidable. These results in softening of matrix and composite pin surface leading to heavy deformation at higher sliding distances. This results to higher volumetric wear loss of matrix and the composite. As shown in the fig. 5 (a) to (c). at all the sliding distance considered . the volumetric wear loss of the composites was much lower when compared with the matrix alloy and reduces with increased content of CNT in the composites. Increase in hardness results in improvement of wear.

3.3.2 Effect of Material loss on Wt% of MMC due to Wear for Extruded Materials

Table. 8

Effect of Material loss on Wt% of MMC

Wt %	0 N	10 N	20 N	30 N

CNT				
0 wt%	4.25	4.228	4.203	4.189
0.1 wt%	3.865	3.847	3.828	3.778
0.2 wt%	4.327	4.299	4.287	4.227
0.3 wt%	4.412	4.4	4.379	4.349
0.4 wt%	4.174	4.155	4.123	4.069
0.5 wt%	2.858	2.834	2.803	2.779

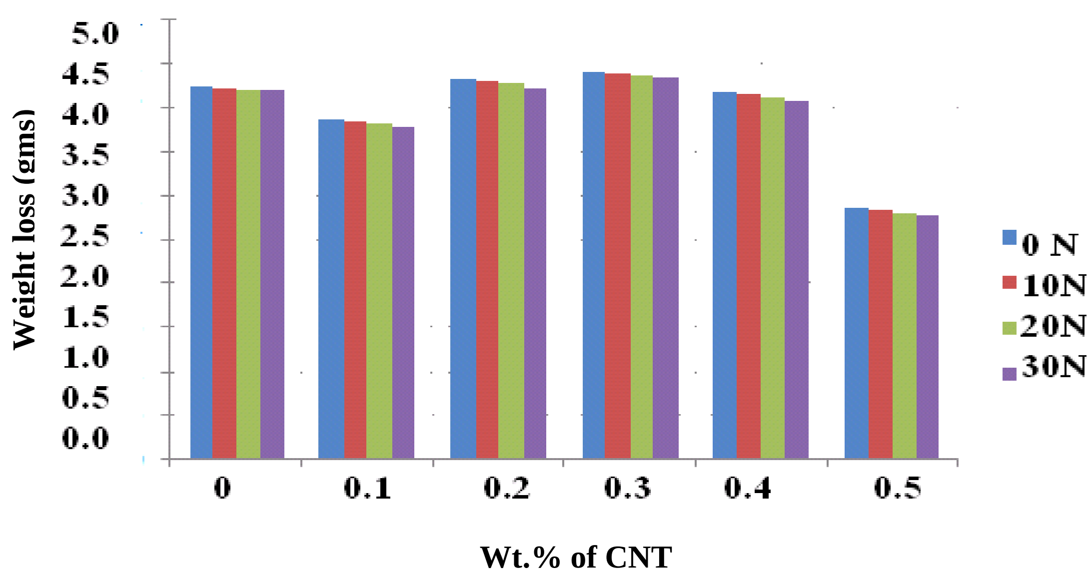

Fig.4. Weight loss of MMCs with various Wt% CNT at different load for Extruded MMCs

It is reported that, by the addition of the CNT its wear property will be decreased by the reinforcement of CNT with Al6061.

3.4 SEM of wear in Extruded MMCs

Fig.5.show the SEM photographs of worn surfaces of extruded Al6061 alloy and its composites at an applied load of 30 N and sliding distance of 3 km.

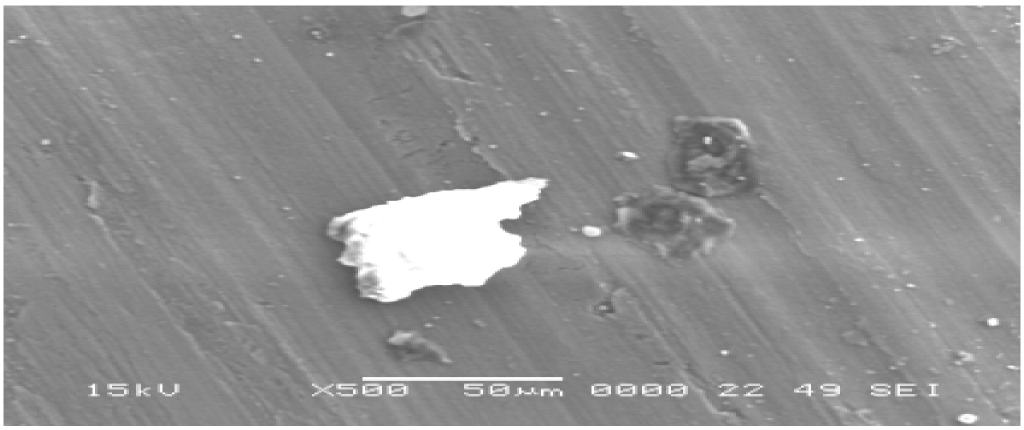

Fig.5 Extruded SEM microstructure

The above fig.5 shown micrograph is of extruded SEM microstructure. we can analyze that the presence of CNT in the material where the black indicates the CNT. The SEM microstructure also indicates the wear surface happens due to wear ,which indicates the surface after wear and also the particles direction after wear caused by the heat. There is evidence of adhesion and ploughing on the Al worn surface, which shows a distinct characteristic of abrasive and adhesive wear. The counterpart pin is seized twice in the wear tests, which may be the result of the weld contact surface metal at some protruding points. 6061Al wear particles on the worn surfaces are laminated by the pin on the contact area, forming plough. SEM images of worn surfaces of the composite and the delamination theory of wear, it can be deduced that the delamination wear could be the main wear mechanism.

4.Conclusions

Al6061 metal matrix composites reinforced with carbon nano tubes was successfully fabricated by stir casting .The microstructure of the carbon nano tubes reinforced composite showed a reasonably uniform distribution of particles and good interracial bonding of dispersed particles with al6061 matrix alloy.There is a good interfacial bonding between Al6061alloy and carbon nanotube metal matrix which improves the hardness of the composites and also the wear behavior of the composites.

Wear behaviour of 6061Al alloy and it's composites was carried out successfully by friction and wear monitor.The carbon nano tubes content in Al6061 alloy plays a significant role in increasing the wear resistance of the material.Al6061 with 0.5% MWCNT have high resistance as indicated by lowest wear. The wear loss tends to decrease with increasing particles volume, which confirms that addition of MWCNT is beneficial in reducing the wear loss of the composite.In adhesive wear,the material loss for Al6061-MWCNT composites is lower when compared to the Al6061 matrix alloy.

Wear loss increases with increasing sliding distance due to the work hardening of the surface leading to abrasion wear.Extrude has a important role in adhesive wear mechanism..Hot extruded specimen gives better wear resistance.

References:

[1].Ray H.Baughman,Anwar A.Zakhidov,walt A de Heer "carbon nanotubes-the Route toward Applications"Science Vol297, (2002)pp. 787-792

[2].Motto Yumura "carbon nanotube Industrial Applications" AIST Today International Edition No10,(8-9).

[3].Rodney S.Ruoff and Donald C.Lorents "Mechanical and thermal properties of carbon nano tubes"Carbon vol33,No7, (1995)pp.925-930

[4].T.W.Ebbesen,H.J.Lezec,H.Hiura,J.W.Bennett,H.F.Gharmi &T.Thio "Electrical conductivity of individual carbon nano tubes"Nature Vol 382, (1996)pp.54-56

[5].Kazuyoshi Tanaka,Tohru Sato,Tokio Yamabe,Kenji Okahara,Kunio Uchida,MottoYamura,Hiroyuki Niino,Satoshi Ohshima,Yasunori kuriki,kiyoshi Yase,Fumikazu, Ikazaki "Electronic properties of carbon nano tube"Chemical physics letters 223, (1994)pp. 65-68

[6].Zhe zhang and Charles M.Lieber "nanotube structure and electronic properties probed by scanning tunneling microscopy"Appl.phys.letter 62(22)pp.2792-2794.

[7]Toru kusumaki,Takuya Hayashi,Kunichi Miyazawa,Hideki Ichinose,Kunio Ito andYoichi Ishida "Discussion on the mechanical behaviopr of carbon nanotube/C60 composite based on observation of interfacial structure" Materials Transactions, JIM,Vol39,No 5(1998)pp.578-581.

[8].Eric W.Wong,Paul E Sheehan,Charles M.Lieber "Nano beam mechanics"Elasticity,strengthandNanotubes".Science Vol.277,(1997)pp.1971-1977

[9].R.Byron Pipes,Pascal Hubert "Helical carbon,nanotube arrays:Mechanical properties"composite science and technology 62(2002)pp.419-428.

[10]Jean-Paul Salvetat-Delmotte,Angel Rubio "Mechanical properties of carbon

nanotubes:a fiber digest for begineers"Carbon40 (2002)pp.1729-1734.

[11]M.M.J Treacy,T.W.Ebbesen & J.M.Gibson "exceptionally high young's modulus observed for Individual carbon nanotubes"Nature,Vol381(1996)pp.678-680.

[12].K.T.Kashyap and R.G.Patil"on young's modulus of multi walled carbon nanotubes"BullMaterial Science Vol31 no2(2008)pp.185-187.

[13]. I. Sridhar Karthic R. Narayanan "Processing and characterization of MWCNT reinforced aluminum matrix composites" J Mater Sci 44(2009)pp. 1750–1756

[14].T. Laha , A. Agarwal,Tim McKechnie,S. Seal "Synthesis and characterization of plasma spray formed carbon nanotube reinforced aluminumcomposite"Material science and EngineeringA38(2004)pp.249-258

[15]Deepak Srivatsva and Chenyu wei "Nanomechanics of carbon nanotubes and composites"App mech Rev Vol.56(2003)pp.215-229.

[16].Chunfeng Deng , XueXi Zhang, Dezun Wang, Qiang Lin, Aibin Li Preparation and characterization of carbon nanotubes/aluminum matrix composites"Materials Letters 61(2007)pp.1725-1728.

[17]C.Srinivasan"An elegant synthesis of multiwalled carbon nanotubes"current Science vol 86,No2,256-257.

[18].Yanchen,Zhong Lin Wang,Jin Song yin,David J.Johnson,R.H.Prince "well aligned graphitic nano-fibers,synthesized by plasma assited chemical vapour deposition"Chemical Physics letter 272(1997)pp.178-182

[19]C.F. Deng , D.Z. Wang, X.X. Zhang, Y.X. Ma "Damping characterization

of carbon nanotubes/aluminium matrix composites.Materials Letters 61(2007)pp.3229-3231.

[20] A.M.K. Esawi, K. Morsi, A. Sayed, A. Abdel Gawad, P. Borah "Fabrication and properties of dispersed carbon nanotube–aluminum composites" Materials Science and Engineering A 508 (2009)pp.167–173.