Influence of Heat Treatment on Strength and Abrasive Wear Behavior of Al6061–MWCNT Metal Matrix Composites

L.H. Manjunatha, Dr. P. Dinesh and S.B. Halesh

Abstract--- *The Aluminum based Metal Matrix Composites are used in the aerospace, marine, automobile and mineral processing industries, due to their improved strength, light weight,high stiffness and wear resistance properties. The widely used reinforcing materials for these composites are silicon carbide, aluminum oxide and graphite in the form of particles or whiskers. The interest in carbon nanotubes (CNTs) as super reinforcements for metallic matrices has been growing considerably over the past few years, largely focusing on investigating their contribution to the enhancement of the mechanical performance of the final composite. As in conventional composites, the orientation of the CNTs, homogeneity of the composite, nanotube matrix adhesion,nanotube aspect ratio and the volume fraction of nanotubes are expected to have significant influences on the properties of the nanocomposite. Aluminum 6061 has been used as matrix material owing to its excellent mechanical properties coupled with good formability and it's wide applications in industrial sector. Addition of Carbon Nano Tube as reinforcement in Al6061 alloy system improves its hardness, tensile strength and wear resistance. In the present investigation, an Al6061 alloy was used as the matrix and Carbon Nano Tubes as the Reinforcing material. The composite was produced using conventional foundry technique i.e.Stir Casting Technique. The CNT was added in 0 wt.%, 0.5wt.%,1 wt.% ,2wt.% , and 3 wt. % to the molten metal. The Ascast Al6061metal matrix alloy and its composites have been subjected to solutionizing treatment at a temperature of 555°C for 8 hour followed by quenching in different media such as air, boiled water and ice. The quenched samples are then subjected to both natural and artificial ageing. Micrograph studies have been carried out to understand the nature of structure. Mechanical properties such as microhardness,compressive strength, and abrasive wear tests have been conducted both on matrix Al6061 and Al6061–CNTcomposites before and after heat treatment. Under heat treatment conditions adopted Al6061–CNT composites exhibited better microhardness ,compressive and reduced wear loss when compared with Al matrix alloy.*

Keywords--- *Microstructure, Metal Matrix Composite, Carbon Nano Tube, Al6061 Alloy, Wear, Heat Treatment*

I. Introduction

METAL matrix composites (MMCs) are gaining popularity due to their improved physical and mechanical properties over monolithic metals. Among the MMCs, Al6061alloy matrix composites are becoming increasingly important due to their applications as lightweight structural materials in the aerospace and automotive industries. Particulate reinforced Al6061composites are becoming more popular, as compared to fiber reinforced.Al6061 composites, due to their increased production rate, reduced reinforcement costs and easier fabrication processes. Micrometer-size SiC particles,graphite are commonly chosen as a reinforcement in Al6061 alloy because of their low cost and easy availability. Mechanical properties of Al6061 alloy such as hardness and modulus can be significantly improved with SiCp,graphite as reinforcement [1–3]. However, micrometer-size SiCp,graphite,tungsten reinforced Al6061 are usually faced with the problem of low ultimate tensile strength and ductility [4,5,6,7] due to particle fracture and particle/matrix interfacial failure. To overcome these limitations, and to look for further improvement in mechanical properties, nanosize reinforcements are studied. Nanosize reinforcements are perceived to be able to impart excellent properties to the Al6061 alloy matrix [4, 8] at a much reduced amount of reinforcement material. Accordingly, the current investigation aims to incorporate Multi walled

L.H. Manjunatha, Associate Professor, Reva Institute of Technology, Bangalore.
Dr. P. Dinesh, Professor, MSRIT,Bangalore.
S.B. Halesh, Associate Professor, Sir M.V.I.T,,Bangalore
PAPER ID: MEG02

carbon nanotubes into Al6061 alloy to enhance its overall physical and mechanical properties.The effects of increasing amount of CNTs on pure Al6061 alloy are investigated. Attempts were made to correlate the effect of increasing weight fractions of CNTs with the properties of the Al6061 nanocomposites.Al6061alloy[4] is heat treatable, and as a result further increase in strength can be expected. However, the major focus is on processing and characterization of Al based composites. Although the synergetic effect of heat treatment and the type of reinforcement plays a dominant role in dictating the final mechanical properties of composites, meager information is available, pertaining to the heat treatment of Al based composites. The present investigation is aimed at studying in detail the effect of quenching media and the ageing duration on the mechanical properties of heat treatable cast Al6061–MWCNT metal matrix composites.

II. MATERIAL SELECTION AND EXPERIMENTAL PROCEDURE

2.1 Materials Selection

Al6061 alloy as matrix material and 0, 0.5, 1, 2 and 3 wt % multi walled carbon nanotubes (MWCNT) were used as the reinforcement phase.

Table 2.1: Typical Properties of Al6061

Component	Al	Mg	Si	Fe	Cu	Zn	Ti	Mn	Chromium	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

2.2 *Typical Heat Treatment/Temper States Al6061-T6*

Solution heat treated and artificially aged.

2.3 Experimental Procedure

A liquid metallurgy route has been adopted to fabricate the cast composites. Al6061 as matrix alloy and Preheated CNT (Multi Walled Carbon Nano Tube) of size 10–30 nm was introduced into the vortex of the effectively degassed Al6061 molten alloy. The molten alloy (Al6061) was stirred for a duration of 10 min using a mechanical stirrer possessing ceramic coated steel impeller. The speed of the stirrer was maintained at 450 rpm. The melt at 725°C was poured into the cast iron molds. The addition of the pre-heat CNT particles in the matrix alloy was varied from 0, 0.5, 1, 2, 3 wt%. The MMC composites and the base Al6061 alloy were subjected to solutionizing at a temperature of 555°C for a duration of 8 hours and then quenched in three different quenching media viz. air, hotwater and ice. Artificial ageing was carried out at 175°C for a duration of 4–10 h in steps of 2 h. Metallographic, hardness, compressive strength and wear tests were carried out on artificial ageing samples.

III. RESULTS AND DISCUSSIONS

Results obtained on arteficially aged (T6), Al6061-MWCNT Composite are produced with various different composition and tested with different loading condition which includes

3.1 SEM Micrographs of the MMCs

The Scanning electronic microscope images of the cast Al6061 and Al6061–CNT composites are shown below.

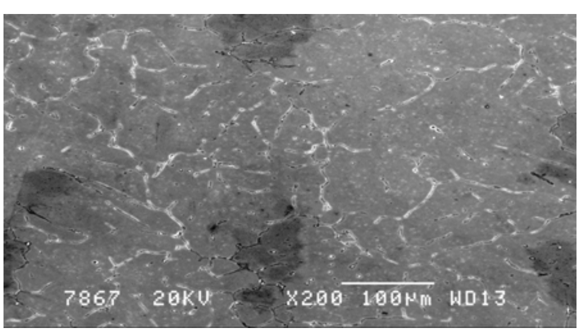


Figure 3.1.1: Al6061 0wt% CNT

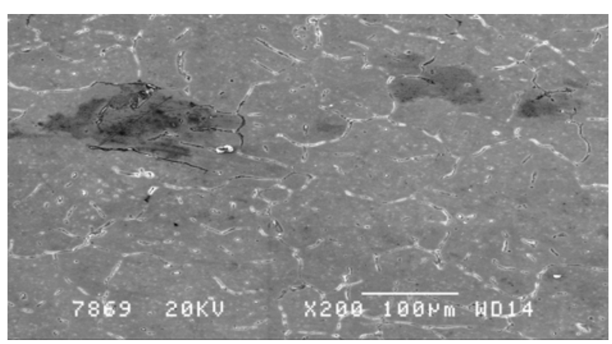


Figure 3.1.2: Al6061-1 wt% CNT

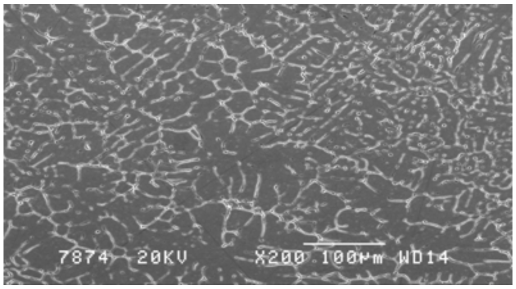


Figure 3.1.3: Al6061 -2 wt% CNT

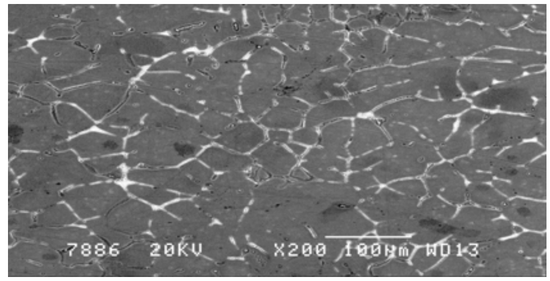


Figure 3.1.4: Al6061-3wt%CNT

The SEM micrographs of Al6061-MWCNT composites are shown in fig 3.1.1 to 3.1.4 The size, density, type of reinforcing particles, and its distribution have a pronounced effect on the properties of particulate composites. The micrographs clearly indicate the evidence of minimal porosity in both the Al6061 alloy and the Al6061–CNT composites. The distribution of CNT in a matrix alloy is fairly uniform. Further the semphotographs reveal an excellent bond between the Al6061 matrix alloy and the MWCNT reinforcement particles.

3.2 Hardness Result

Results obtained pertaining to various tests on Al6061-MWCNT Composite are produced with various different compositions and tested with different loading condition.

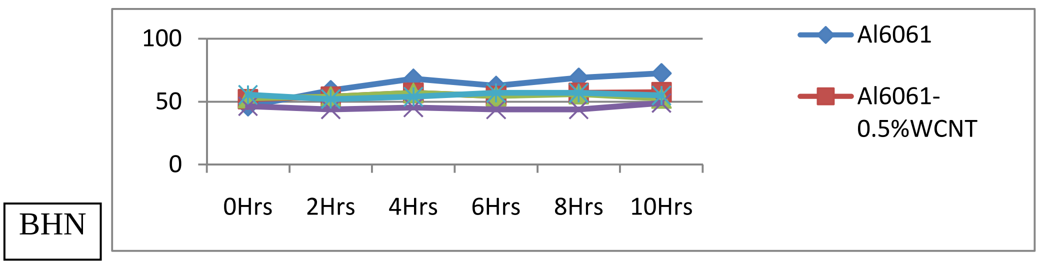


Figure 3.2.1: Ageing Time in Hrs

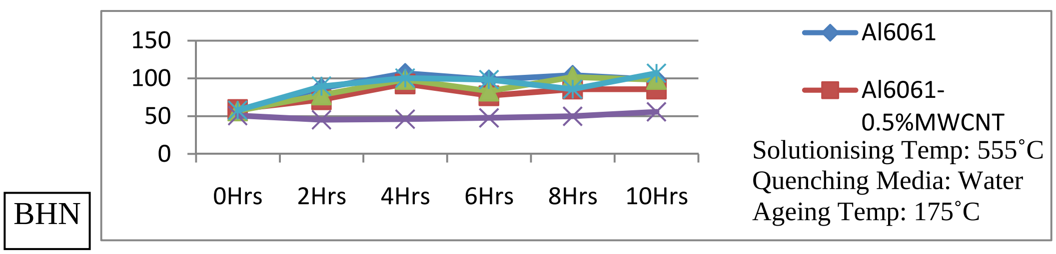


Figure 3.2.2: Ageing Time in Hrs

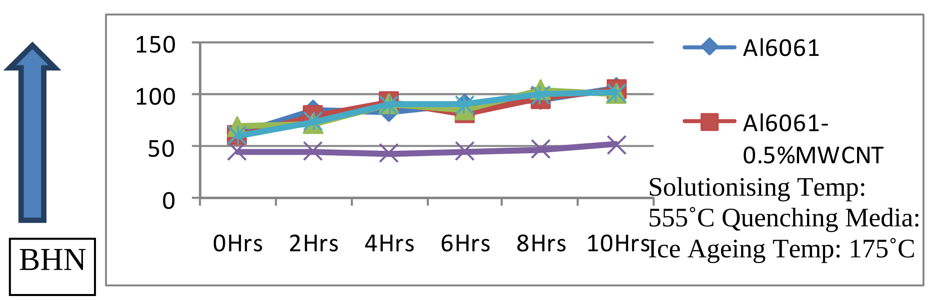
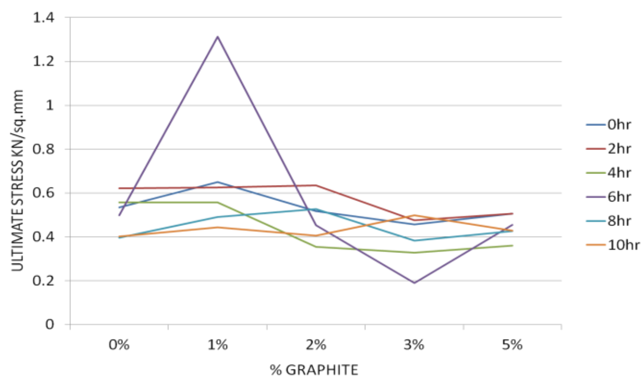


Figure 3.2.3: Ageing Time in Hrs

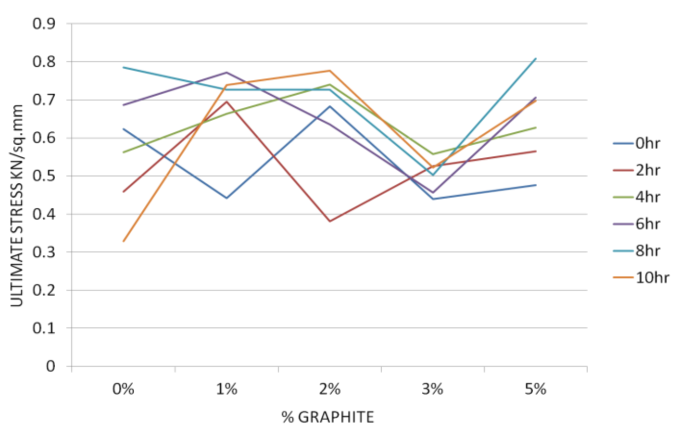
- The above graphs revealed Hardnesse of composites increased significantly with increased content of MWCNT in different quenching media and ageing hrs from 0-10hr.

For a solutionizing temperature of 555^{0}C, solutionizing duration of 8Hrs, quenching in different media, ageing temperature of 175^{0}C with different duration of time. Quenching media and ageing duration significantly alters the microhardness of both the Al6061 matrix alloy and its MWCNT composites. The maximum hardness was observed for both the matrix alloy and the studied composites for ageing duration of different time intervals, while the quenching media was ice. In all the quenching media, and under all ageing times studied, composites exhibit higher hardness when compared with matrix alloy. Ageing of Al6061 matrix alloy and its MWCNT composites for a duration from 8hr at a temperature of 175^{0}C upon ice quench after solutionizing results in obtaining maximum hardness of the matrix alloy and its composites. Ice quenching and ageing from 8hr, the Al6061-3 wt % MWCNT exhibited a maximum improvement in hardness, while the quenching media is air and water; it is observed that the microhardness is less ascompared to the ice quench media. But as the ageing duration increases the microhardness also increases for all quenching media.

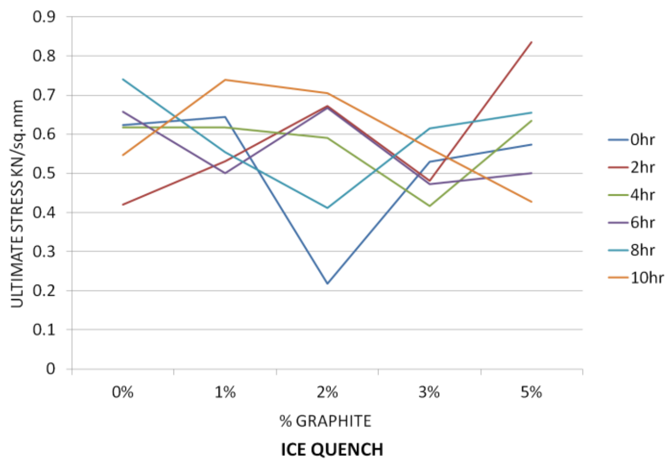
3.3 Compressive Strength Results



AIR QUENCH



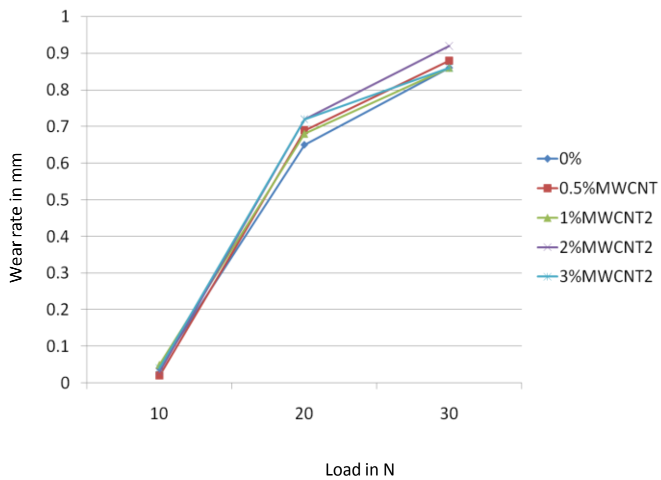
WATER QUENCH



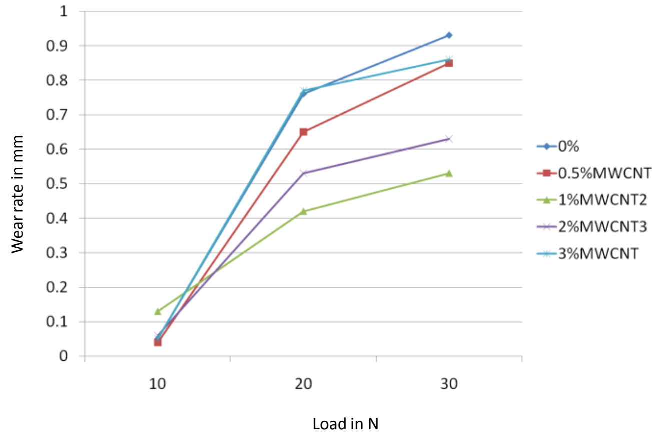
- Fig.3.3 shows the above graphs revealed Compressive strength of composites increased significantly with increased content of MWCNT in different quenching media and ageing hrs from 0-10hr.

3.4 Abrasive Wear Results

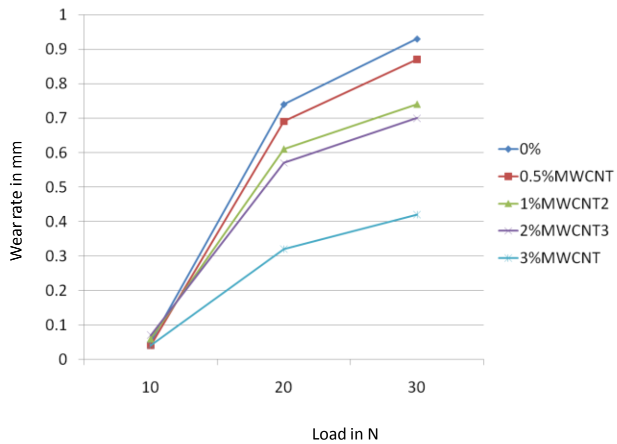
The variation of abrasive wear loss of Al6061-MWCNT composites under different loads for different ageing duration quenched in different media are shown in the below graphs.



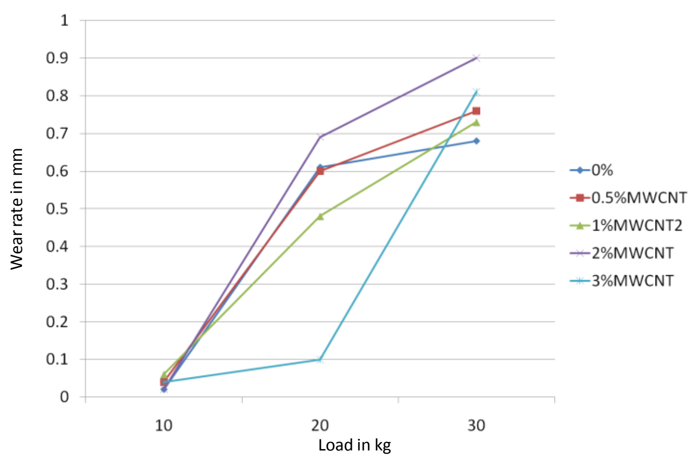
Graph11:The above graph shows the variation of wear rate with change in load (6hr Water quench)



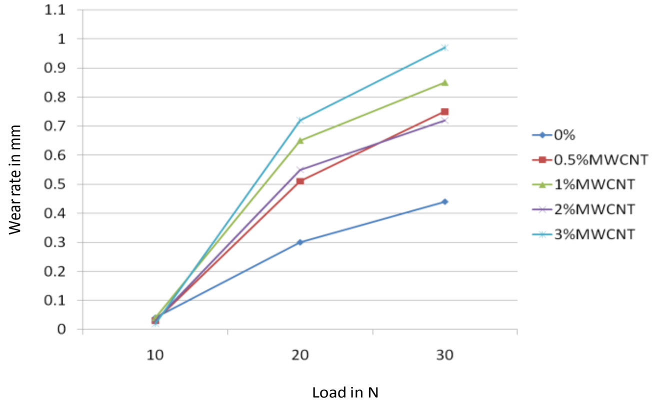
Graph13:The above graph shows the variation of wear rate with change in load (8hr Air quench)



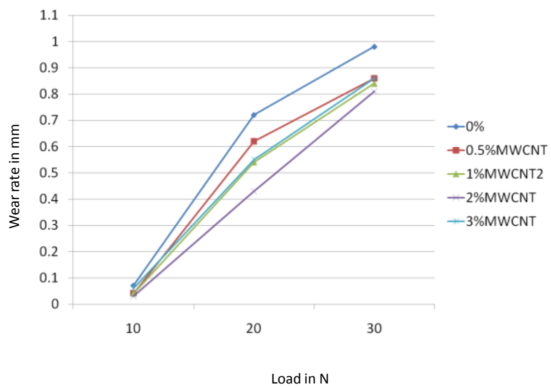
Graph14:The above graph shows the variation of wear rate with change in load (8hr Water quench)



Graph15:The above graph shows the variation of wear rate with change in load (8hr Ice quench)



Graph16:The above graph shows the variation of wear rate with change in load (10hr Air quench)



Graph17:The above graph shows the variation of wear rate with change in load (10hr Water quench)

It is observed that the amount of MWCNT reinforcement in the Al6061matrix alloy have profound influence on the abrasive wear behavior of matrix alloy and its composites at a given load, Increased content of MWCNT in the Al6061 (matrix) alloy enhances the abrasive wear resistance of composites which can be attributed to the fact that MWCNT itself being hard can combat the abrasion, thereby resulting in lower material removal. Higher the hardness of composites better will be its abrasion resistance. Composites possessed the lowest abrasive loss when compared to matrix alloy.

3.5 SEM Micrographs of the Worn Surface the Composite

SEM micrographs of the worn surfaces after the wear test under velocity 1 m/s; time 30min

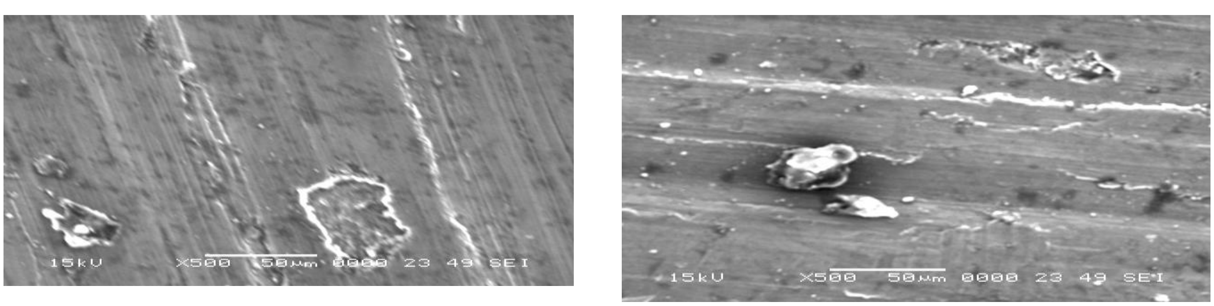


Figure 3.5.1: SEM Micrographs of the Worn Surfaces after the Wear Test under Velocity 1 m/s; time 30min; (a) Load 10N and (b) 20N

Examination of the worn surfaces of Al6061alloy-MWCNTcomposites under the SEM after wear test shows that under the load of 10N, the worn surface has relatively less ploughing and cutting, as shown in Figure 3.5.1(a). However, at the load of 20N, fractured MWCNT particles are frequently present on the worn surface, as shown in Figure 3.5.1 (b).

IV. CONCLUSIONS

- Microstructural studies clearly reveal a uniform distribution of CNT in the matrix alloy with an excellent bond between the matrix alloy and reinforcement.
- Microhardness of composites increased significantly with increased content of MWCNT. Heat treatment has a significant effect on microhardness of Al6061 matrix alloy and its composites. Ice quenching followed by increased duration of ageing time resulted in maximum hardness of matrix alloy and its composites.
- Compressive strength of composites increased significantly with increased content of MWCNT. Heat treatment has a significant effect on Al6061 metal matrix alloy and its composites.
- The materials Al6061 with varying percentages of MWCNT content which are quenched in ice followed by more duration of ageing time resulted in maximum ultimate compression strength.
- Adhesive wear loss of composites decreases, with the increase in content of MWCNT in the matrix alloy under identical test condition. Heat treatment has a profound effect on adhesive wear behavior of matrix alloy and its composites.

REFERENCES

[1] C S Ramesh,N R PrabhuSwamy, and T Chandrashekar Effect of heat treatment on strength and abrasive wear behavior of Al6061-SiCp composites, Bull. Mater. Sci., Vol. 33, No 1, pp. 49-54. Indian Academy of sciences.

[2] G. B. Veeresh Kumar, C. S. P. Rao, N. Selvaraj,Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No.1, pp.59-91, 2011.

[3] A. Baradeswaran, A. Elayaperumal, “Effect of Graphite Content on Tribological behaviour of Aluminium alloy”European Journal of Scientific ResearchISSN 1450-216X Vol.53 No.2 (2011), pp.163-170 © EuroJournals Publishing, Inc. 2011. http://www.eurojournals.com/ejsr.html.

[4] G. Mrówka-Nowotnik, “Influence of chemical composition variation and heat treatment on microstructure and mechanical properties of 6xxx alloys”, International Scientific Journal Published monthly by the World Academy of Materials and Manufacturing Engineering,Vol 46, Issue 2, Dec 2010, pp. 98-107.

[5] T.V. Christy, N. Murugan and S. Kumar, “A Comparative Study on the Microstructures and Mechanical Properties of Al 6061 Alloy and the MMC Al6061/TiB2/12P”, Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.1, pp.57-65, 2010jmmce.org Printed in the USA.

[6] Arun Kumar M. B,and R. P. Swamy, “Evaluation of mechanical properties of Al6061,flyash and E-glass fiber reinforced hybrid metal matrix composites, ARPN Journal of Engineering and Applied Sciences”, VOL. 6, NO. 5, MAY 2011, ISSN 1819-6608, ©2006-2011 Asian Research Publishing Network (ARPN).www.arpnjournals.com.

[7] C.S. Goh, J. Weia, L.C. Lee , M. Gupta “Simultaneous enhancement in strength and ductility by reinforcing magnesium with carbon nanotubes” Materials Science and Engineering A 423 (2006) 153–156

[8] M.K.Surappa,”Al matrix composites Challengesand opportunities”,Sadhan aVol. 28, Parts 1 & 2, February/April 2003, pp. 319–334.

[9] R.T. Holt, M.D. Raizenne and W. Wallace and D.L. DuQuesnay “RRA Heat Treatment of Large Al 7075-T6 Components” Paper presented at the RTO AVT %rkshop on “New Metallic Materials for the Structure of Aging Aircraft”, held in Corfu, Greece, 19-20 April 1999, and published in RTO kfp-25.

[10] LI Jin-feng, PENG Zhuo-wei, LI Chao-xing, JIA Zhi-qiang, CHEN Wen-jing, ZHENG Zi-qiao “Mechanical properties, corrosion behaviors and microstructures of 7075 aluminium alloy with various aging treatments”trans. Nonferrous Met. Soc. China 18(2008) p755-762