Studies on Effect of Heat Treatment and Ice Quench Age Hardening on Microstructure, Strength, Abrasive Wear Behavior of Al6061–MWCNT Metal Matrix Composites

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Abstract- **Aluminium6061–based composites have received considerable attention for aerospace and industrial sector applications because of their low density and high stiffness. Addition of Multi-walled Carbon Nano Tube (MWCNT) as reinforcement in Al6061 alloy system improves its hardness, strength and wear resistance. In the present investigation, an Al6061 alloy was used as the matrix and Multi-walled Carbon Nano Tubes(MWCNT) as the Reinforcing material. The composite was produced using Stir Casting Technique. The MWCNT was added by 0,0.5wt.%,1 wt.% ,2wt.% , and 3 wt.% to the molten metal. The As cast 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 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 hardness and abrasive wear tests have been conducted both on Al6061 and Al6061–MWCNT composites before and after heat treatment. Under heat treated conditions adopted Al6061–MWCNT composites exhibited better hardness and reduced wear loss when compared with Al 6061 alloy.**

Keywords- Microstructure, Metal matrix composite, Multi-walled Carbon Nano Tube(MWCNT), Al6061 alloy, wear, Heat treatment, Age hardening

1.INTRODUCTION:

Aluminium based particulate Metal Matrix Composites (MMCs) offer significant performance advantages over pure metals and metallic alloys. The desirable properties of these materials give them many potential applications in areas such as in the automotive, aerospace and sporting goods industries. MMCs can be classified into one of three broad categories, namely particle reinforced MMCs, short fiber reinforced MMCs and continuous fiber reinforced MMCs. Among the MMCs, Aluminium 6061 alloy matrix composites are becoming increasingly important due to their applications as lightweight structural materials in the aerospace and automotive industries. 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 present investigation aims to incorporate carbon nanotubes(MWCNT) into Al6061 to enhance its overall physical and mechanical properties.The effects of increasing amount of MWCNTs on Al6061 are investigated. Attempts are made to correlate the effect of increasing weight fractions of CNTs with the properties of the Al6061 nanocomposites. 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 SiC, graphite as reinforcement [1,2,3,4]. However, micrometer-size SiC particles,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 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 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 are made to correlate the effect of increasing weight fractions of CNTs with the properties of the Al6061 nanocomposites.Al6061 alloy[1,4] 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. The present investigation is aimed at studying in detail the effect of ice quenching media and the ageing duration on the mechanical properties of heat treatable cast Al6061–MWCNT composites.

2.MATERIAL SELECTION AND EXPERIMENTAL PROCEDURE

Al6061 alloy as matrix material and 0.5,1,2 and 3 wt.% multi walled carbon nanotubes were used as the reinforcement phase.Tables 2.1 and 2.2 show the various properties of Al6061 and CNT along with a comparison with other engineering materials.

Table.2.1 Chemical composition of Al6061

C ompo nent	A l	g	i	e	u	n	i	n	C hromi um	C the rs
A mount (Wt. %)	b alan ce	.8 - 1. 2	. 4 – 0 . 8	ax . 0. 7	.1 5- 0. 40	ax . 0. 25	ax . 0. 15	ax . 0. 15	0. 04- 0.35	0 .05

Table.2.2 Comparison of Mechanical properties of other materials with MWCNT

Material	Young's modulus (TPa)	Tensile strength (GPa)	Elongation at break (%)
MWNT(Multi Walled Carbon Nano Tubes)	0.2–0.8–0.95	11–63–150	15.4
Stainless steel	0.186–0.214	0.38–1.55	15–50
Kevlar–29&149	0.06–0.18	3.6–3.8	~2
Aluminium6061	69-70Gpa	0.31	20

2.3 Experimental Procedure

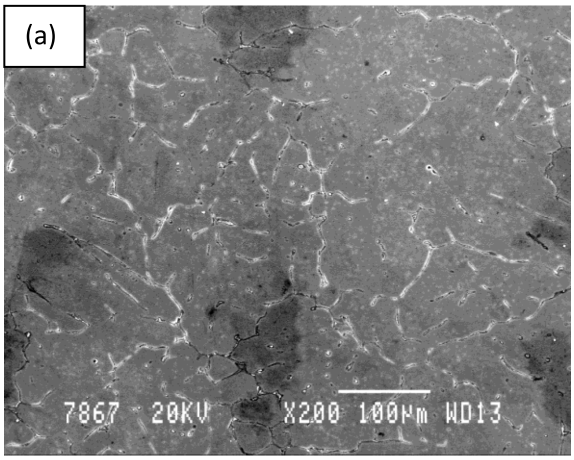
A stir casting method has been adopted to develop the cast composites. Al6061 alloy as matrix and Preheated MWCNT(Multi Walled Carbon Nano Tube) of size 10–30 nm was reinforced material introduced into the vortex of the effectively degassed Al6061 molten alloy. The molten alloy(Al6061) was stirred for a duration of 10 min using a mechanical stirrer possessing ceramic coated steel impeller. The speed of the stirrer was maintained at 400-450 rpm. The melt at 725°C was poured into the cast iron molds. The addition of the pre-heat MWCNT 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 quenching media viz. Ice. Artificial ageing was carried out at 175°C for a duration of 0–10 hrs in steps of 2 hrs. Metallographic, hardness, compressive strength and wear tests were carried out on artificial aged samples.

RESULTS AND DISCUSSIONS

Results obtained on artificially aged (T6), Al6061-MWCNT Composites were produced with various compositions and tested with different loading conditions.

3.1 SEM micrographs of the MMCs

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



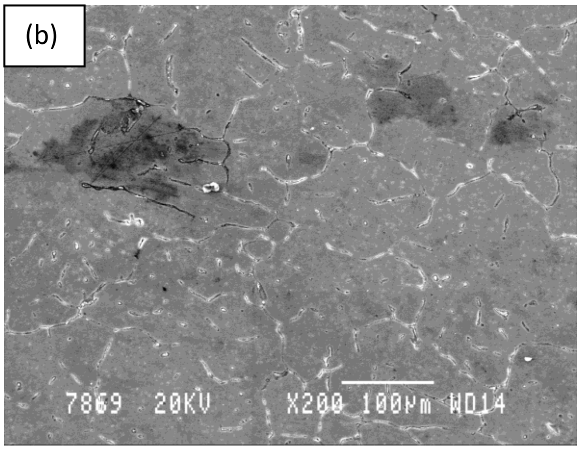
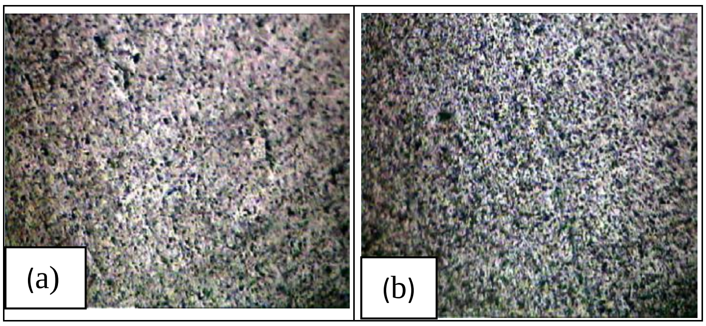


Fig.1(b) Al6061- wt% MWCNT Fig.1(b) Al6061-
wt% MWCNT

3.2 Microscope micrographs of the MMCs

The optical microscope images of the cast Al6061 and Al6061–MWCNT composites are shown fig.2(a) to (f). below. Artificial ageing was carried out at 175°C for a duration of 0–10 hrs in steps of 2 hrs as shown in fig.2(a) to (f).



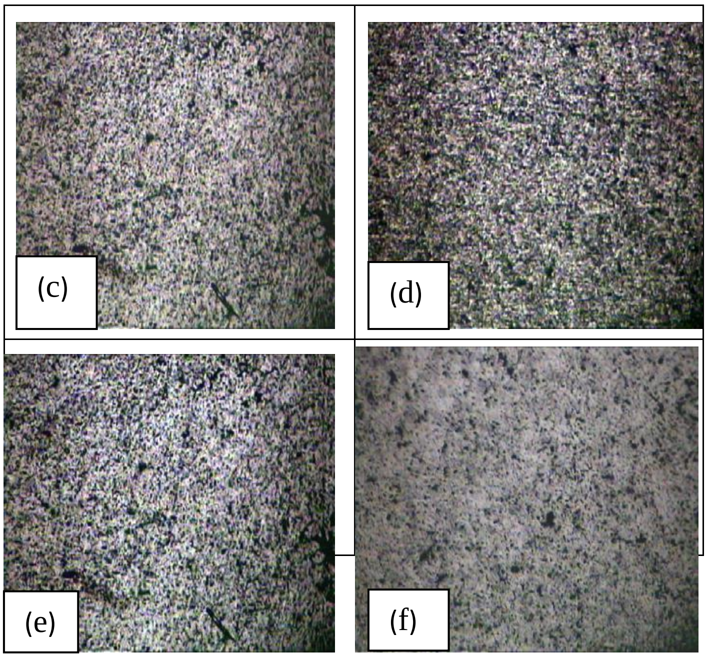


Fig.2(a) to (f). Microstructure of the MMC developed obtained by an Optical Microscope

Micrograph studies have been carried out to understand the nature of structure for Artificial ageing was carried out at 175°C for a duration of 0–10 hrs in steps of 2 hrs as shown in fig.2(a) to (f). The micrographs fig.2 (a) to (f) clearly indicate the evidence of minimal porosity in both the Al6061 alloy and the Al6061–MWCNT composites. The distribution of MWCNT in a matrix alloy is fairly uniform. The optical microscope micrographs reveal an excellent bond between the matrix alloy and the reinforcement particles. A MWCNT with a clean surface was embedded on the grain boundary of the Al6061 matrix. The interfaces of MWCNTs–Al6061 bonded well, and no reactant was formed in the present techniques. Fig.2 (e) & (f) show the matrix grains in the composites, it was obviously found that the matrix grains kept equi-axes and the grain size of the matrix was as fine as 200 nm. Fig.2(c) and 2(d) shows some MWCNTs with an obviously tubular structure, which suggested that the MWCNTs had been embedded into the Al6061 matrix. Meanwhile, MWCNTs were dispersed well in the Al6061 matrix, and some were pulling out. A uniform distribution of MWCNT particles without voids and discontinuities can be observed from these micrographs. It was also found that there was good bonding between matrix material and MWCNT particles; however no gap is observed between the particle and matrix.

3.2 Hardness result

The specimens were age hardened and the BHN values for different conditions are in the fig.3

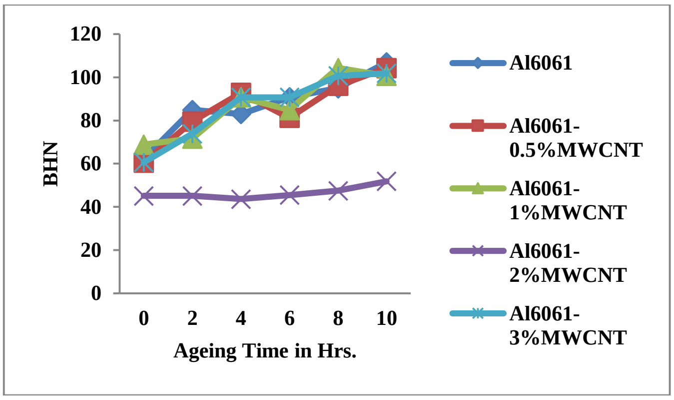


Fig.3. Variation of hardness with increase in ageing time under heat treatment condition quenched in Ice.

For a solutionizing temperature of 555^{0}C, solutionizing duration of 8Hrs, quenching in water media, ageing temperature of 175^{0}C with different duration of time. Quenching ice 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 Al6061 alloy matrix & MWCNT reinforced composites. The study revals that for ageing duration of different time intervals, while the quenching media was Ice. In ice quenching media, and under all ageing times studied, composites exhibit higher hardness shown in fig.3.

Ageing of Al6061 matrix alloy and its MWCNT composites for a duration for 10hr at a temperature of 175^{0}C upon ice quench after solutionizing results is obtaining maximum hardness of the matrix alloy and its composites. Ice quenching and ageing from 8hr, the Al6061-1 wt % MWCNT exhibited a maximum improvement in hardness.

3.4 Abrasive wear

The variation of abrasive wear loss of Al6061-MWCNT composites under different loads for different ageing duration quenched in ice media are shown in the fig.4.

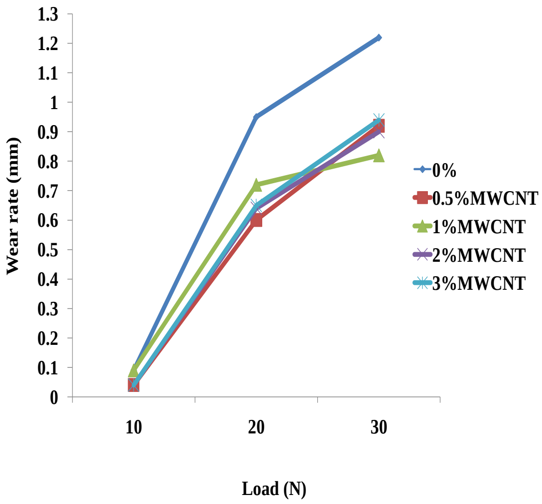


Fig.4. wear rate v/s load (0 hr Ice quench)

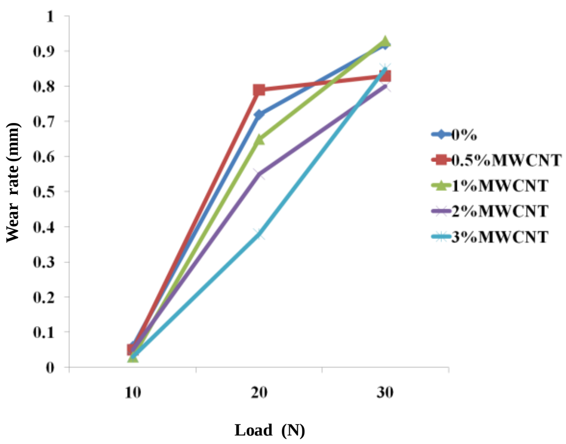


Fig.5. wear rate v/s load (2 hr Ice quench)

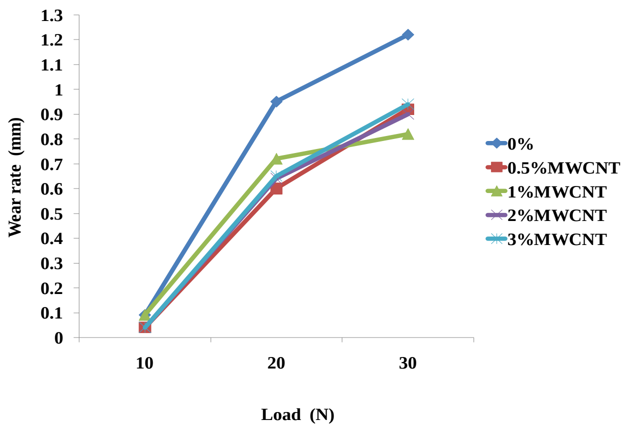


Fig.6. wear rate v/s load (4 hr Ice quench)

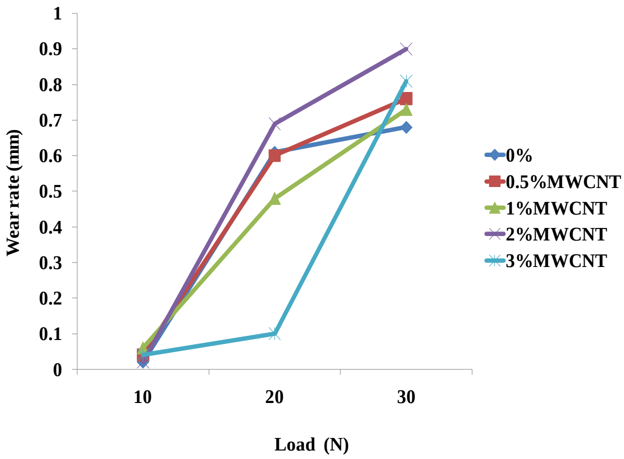


Fig.7. wear rate v/s change in load (8 hr Ice quench)

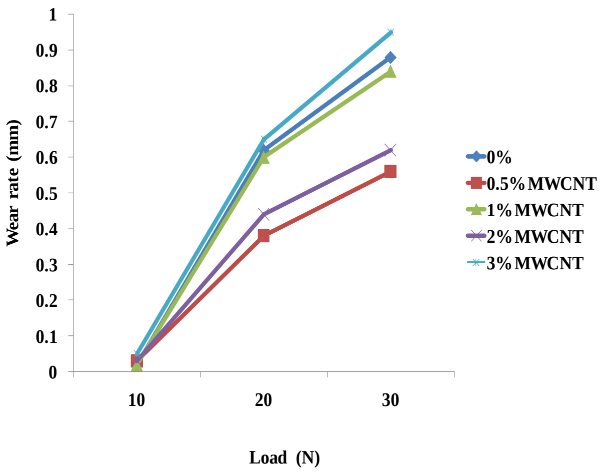


Fig.8. wear rate v/s load (10 hr Ice quench)

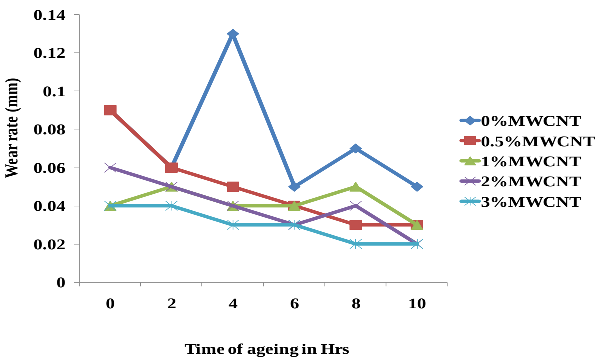


Fig.9. the variation of wear rate with increasing percentages of MWCNT content in Al6061 for different hours of ageing time under 10N load for ice quenching.

ISSN: 2278-0181

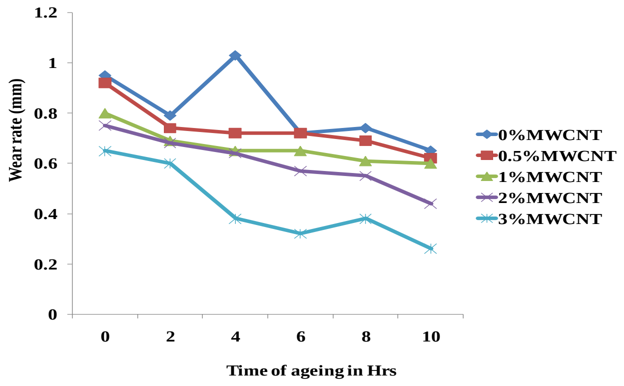


Fig.10. the variation of wear rate with increasing percentages of MWCNT content in Al6061 for different hours of ageing time under 20N load for ice quenching.

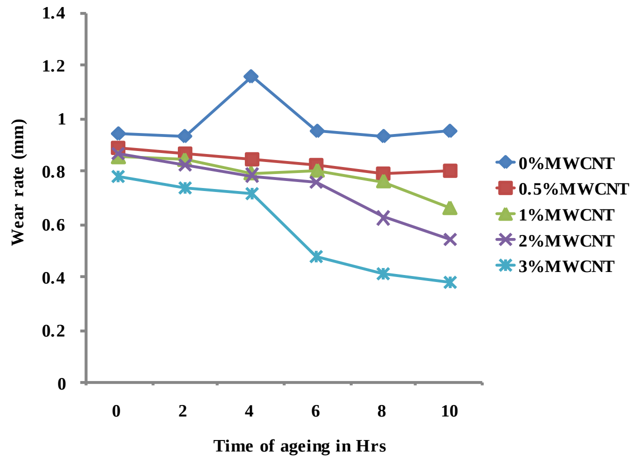


Fig.11. the variation of wear rate with increasing percentages of MWCNT content in Al6061 for different hours of ageing time under 30N load for ice quenching.

It is observed from the above fig.4 to 11 that the amount of MWCNT reinforcement in the Al6061matrix alloy have influence on the abrasive wear behavior of Al6061 alloy and it's MWCNT composites at a given load, Increased percentage 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 combine 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 Al6061 matrix alloy.

3.5 Ultimate Compression Strength Graphs

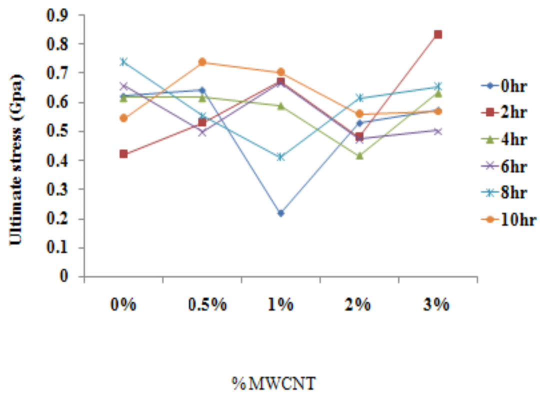
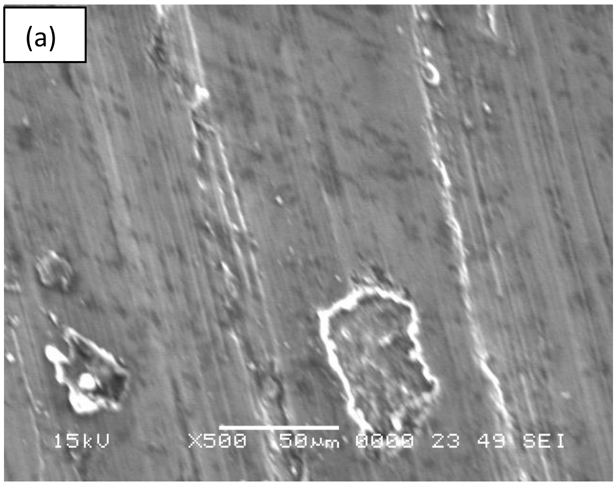


Fig.12.The variation of ultimate stress for different Al6061-MWCNT Composites for different ageing times quenched in ice.

Compression strength increases with increasing percentage of MWCNT particulates. This may be due to the hardening of the base alloy by MWCNT particulates. Ice quench fig.12. shows ultimate compressive strength increases with increasing MWCNT content. This may be due to the presence of hard MWCNT particulates.

3.6 SEM micrographs of the worn surface of the composite

Fig. 13 shows SEM micrographs of the worn surfaces after the wear test under velocity of 1 m/s, for a run of 30min.



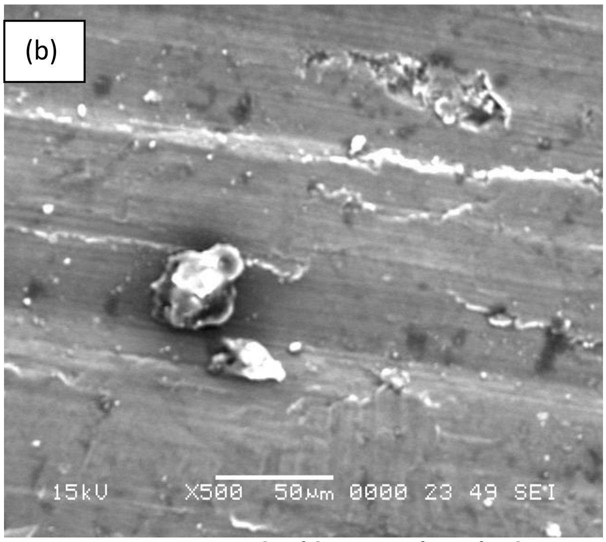


Fig.13. SEM micrographs of the worn surfaces after the wear test under velocity 1 m/s; time 30min; (a) load 10N and (b) 20N

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 13.(a). However, at the load of 20N, fractured MWCNT particles are frequently present on the worn surface, as shown in Figure 13. (b).

4.CONCLUSIONS

The study comprised of studying the various properties of Al6061 and Al6061-MWCNT MMC due to age hardening. In conclusion it is seen that Microstructural studies clearly reveal a uniform distribution of CNT in the matrix alloy with an excellent bond between the matrix alloy and reinforcement. Macrohardness of composites increased significantly with increased content of MWCNT. Heat treatment has a significant effect on microhardness of Al6061 matrix alloy and its composites. Heat treatment has a significant effect on Al6061 metal matrix alloy and its composites. 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.

ACKNOWLEDGMENT

The authors wish to thank Managements , Principals and Heads of Department, Mechanical Engineering of M.S.Ramaiah Institute, Bangalore and Reva Institute of Technology and Mangement, Bangalore for their support in provoding research facilities and conducive environment for carrying out research.

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