

## RESEARCH ARTICLE

## Studies on effect of heat treatment and water quench age hardening on microstructure, strength, abrasive wear behaviour of Al6061-MWCNT metal matrix composites

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### Abstract

Aluminium 6061-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 wears resistance. In the present investigation, an Al6061 alloy was used as the matrix and MWCNT as the reinforcing material. The composite was produced using stir casting technique. The MWCNT was added by 0.5 wt.%, 1 wt.%, 2 wt.% and 3 wt.% to the molten metal. The Ascast Al6061-metal matrix alloy and its composites have been subjected to solutionizing treatment at a temperature of 555°C for 8 h followed by quenching in boiled water. 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, Al6061 alloy, heat treatment, age hardening.

### 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 light weight 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 (Ramesh *et al.*, 2010; Veeresh Kumar *et al.*, 2011; Swamy *et al.*, 2011; Baradeswaran and Elayaperumal, 2011). However, micrometer-size SiC particles, graphite, tungsten reinforced Al6061 are usually faced with the problem of low ultimate tensile strength and ductility (Baradeswaran *et al.*, 2011; Mrówka-Nowotnik *et al.*, 2010; Christy *et al.*, 2010; Arun Kumar *et al.*, 2011) 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 (Baradeswaran *et al.*, 2011; Goh *et al.*, 2006) 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 (Ramesh *et al.*, 2010; Baradeswaran *et al.*, 2011) 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 quenching media and the ageing duration on the mechanical properties of heat treatable cast Al6061-MWCNT composites.

Table 1. Chemical composition of Al6061.

| 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. Comparison of mechanical properties of other materials with MWCNT.

| Material          | Young's modulus (TPa) | Tensile strength (GPa) | Elongation at break (%) |
|-------------------|-----------------------|------------------------|-------------------------|
| MWNT              | 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 and 149 | 0.06-0.18             | 3.6-3.8                | ~2                      |
| Aluminium6061     | 69-70Gpa              | 0.31                   | 20                      |

**Materials and methods**

*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. Table 1 and 2 show the various properties of Al6061 and CNT along with a comparison with other engineering materials.

*Experimental procedure:* A stir casting method has been adopted to develop the cast composites. Al6061 alloy as matrix and preheated MWCNT 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 duration of 8 h and then quenched in quenching media viz. hot water. Artificial ageing was carried out at 175°C for duration of 0-10 h in steps of 2 h. Metallographic, hardness, compressive strength and wear tests were carried out on artificial aged samples.

**Results and discussion**

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

*SEM micrographs of the MMCs:* The scanning electronic microscope images of the cast Al6061 and Al6061 MWCNT composites are shown in figure 1a and b. The micrographs 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 SEM photographs reveal an excellent bond between the matrix Al6061 alloy and the MWCNT reinforcement particulate.

*Microscope micrographs of the MMCs:* The optical microscope images of the cast Al6061 and Al6061 MWCNT composites are shown in figure 2a-f.

Fig. 1a. SEM micrographs of Al6061 0.5 wt. % MWCNT.

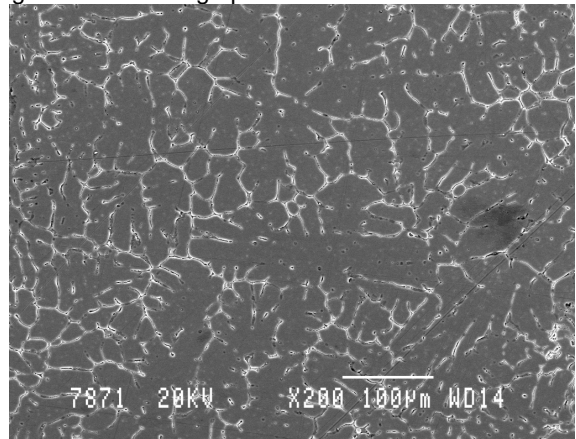
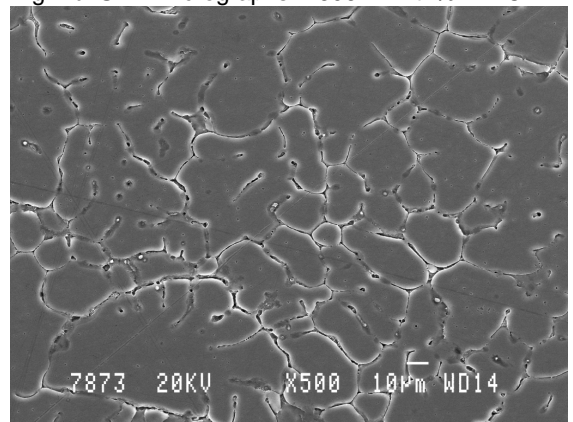


Fig. 1b. SEM micrographs Al6061 1 wt. % MWCNT.



Artificial ageing was carried out at 175°C for duration of 0-10 h in steps of 2 h. Micrograph studies have been carried out to understand the nature of structure for artificial ageing was carried out at 175°C for duration of 10 h in steps of 2 h as shown in figure 2a to f. The micrographs 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. 2a-f. Optical microscope images of the cast Al6061 and Al6061 MWCNT composites.

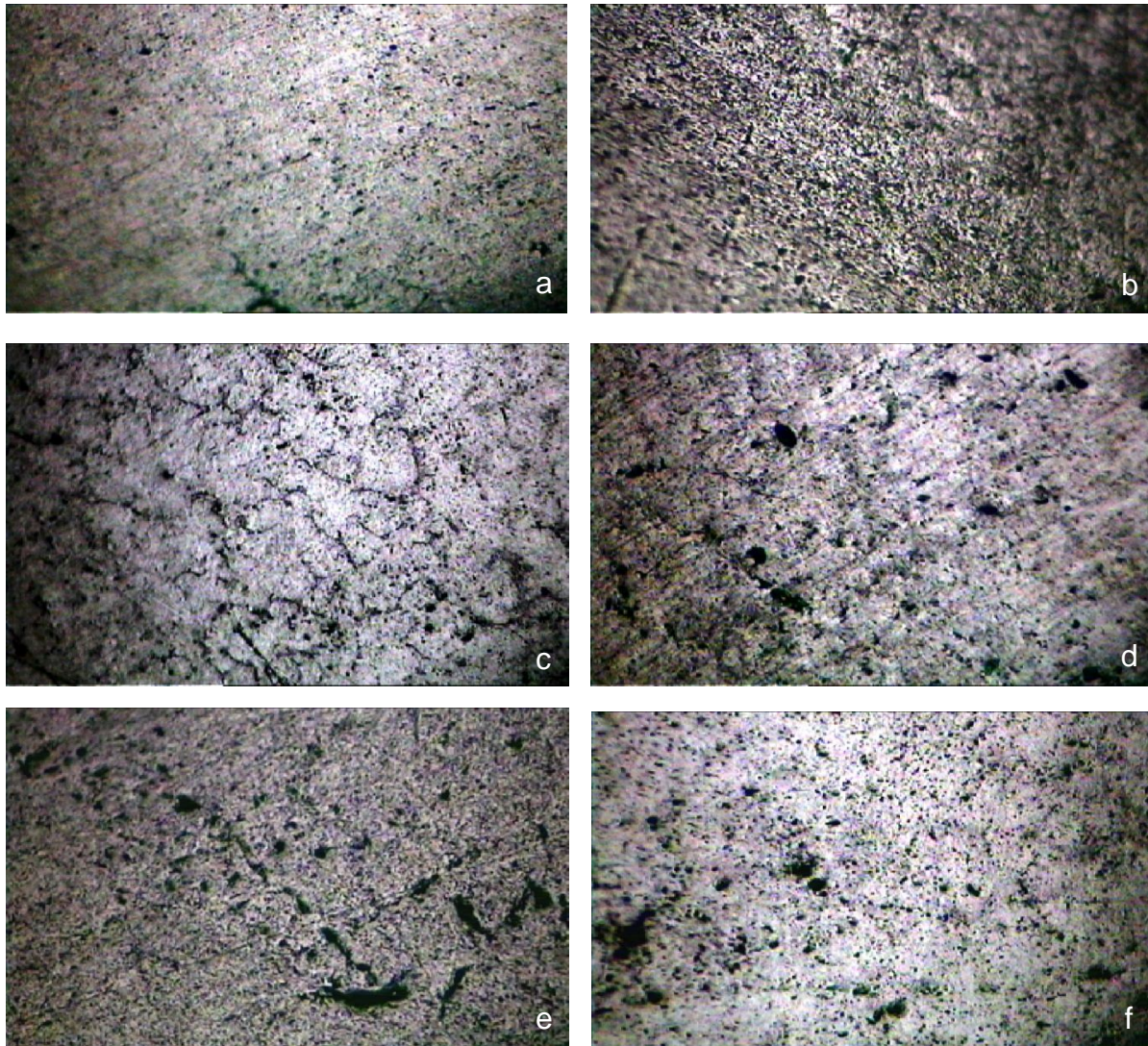


Figure 2e and f show the matrix grains in the composites, it was obviously found that the matrix grains kept equi-axes and the grain size of the matrix was as fine as 200 nm. Figure 2c and d shows some MWCNTs with an obviously tubular structure, which suggested that the MWCNTs had been embedded into 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.

**Hardness result:** The specimens were age hardened and the BHN values for different conditions are shown in figure 3. For a solutionizing temperature of 555°C, solutionizing duration of 8 h, quenching in water media, ageing temperature of 175°C with different duration of time.

Quenching water media and ageing duration significantly alters the micro-hardness of both the Al6061 matrix alloy and its MWCNT composites. The maximum hardness was observed for both the Al6061 alloy matrix and MWCNT reinforced composites. The study reveals that for ageing duration of different time intervals, while the quenching media was boiled water. In water quenching media, and under all ageing times studied, composites exhibit higher hardness when compared with matrix alloy as shown in figure 3. Ageing of Al6061 matrix alloy and its MWCNT composites for a duration for 10 h at a temperature of 175°C upon water quench after solutionizing results is obtaining maximum hardness of the matrix alloy and its composites. Boiled water quenching and ageing from 10 h, the Al6061-3 wt.% MWCNT exhibited a maximum improvement in hardness.

**Abrasive wear:** The variation of abrasive wear loss of Al6061-MWCNT composites under different loads for different ageing duration quenched in water media are shown in the figure 4.

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

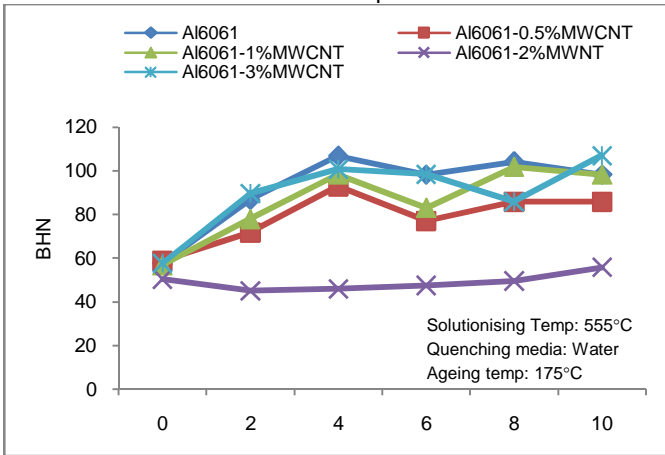


Fig. 6. Wear rate v/s load (6 h water quench).

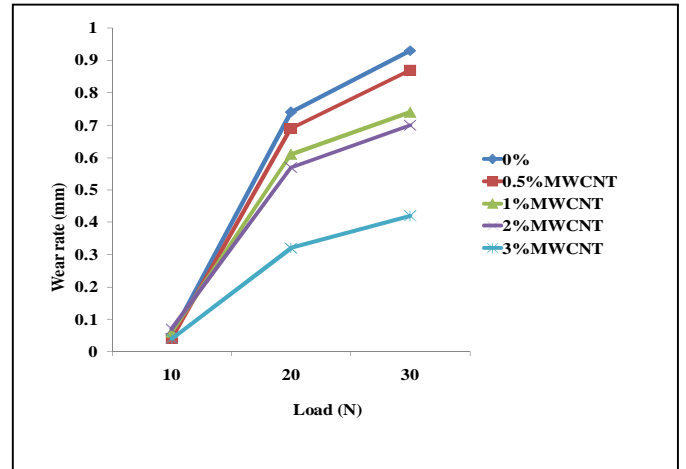


Fig. 4. Wear rate v/s load (2 h water quench).

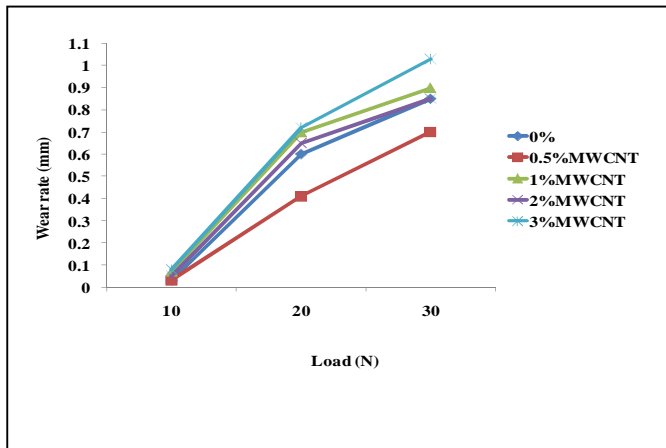


Fig. 7. Wear rate v/s load (8 h water quench).

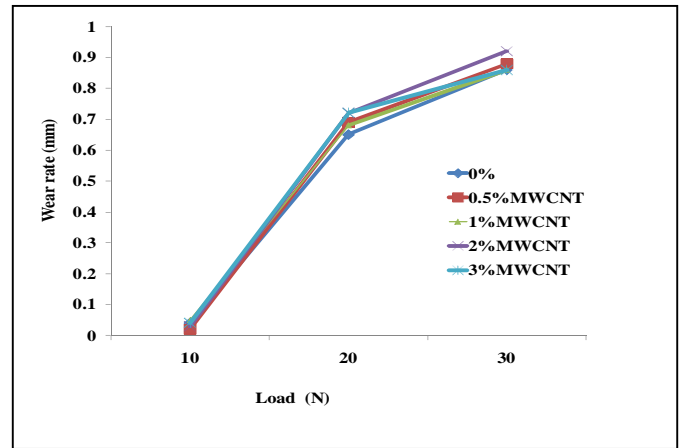


Fig. 5. Wear rate v/s load (4 h water quench).

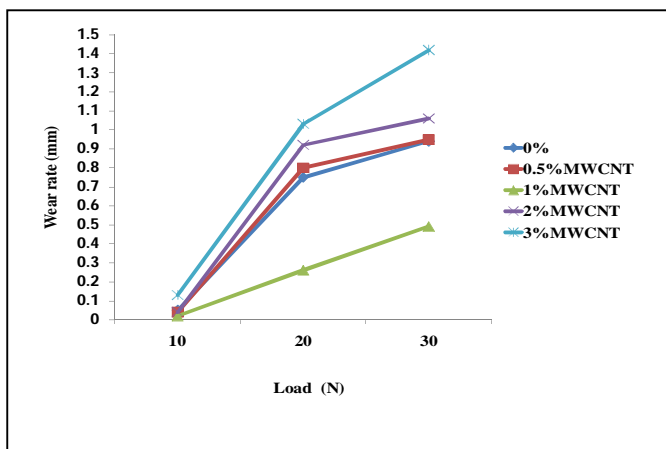


Fig. 8. Wear rate v/s load (10 h water quench).

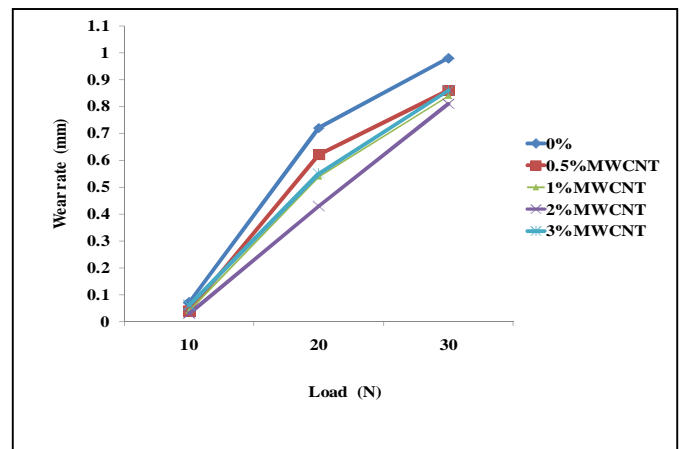


Fig. 9. The variation of wear rate with increasing percentages of MWCNT content in Al6061 for different hours of ageing time under 10 N load for water quenching.

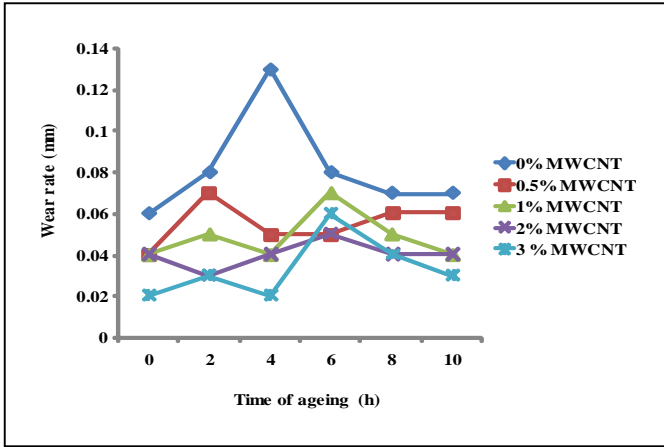


Fig. 10. The variation of wear rate with increasing percentages of MWCNT content in Al6061 for different hours of ageing time under 20 N load for water quenching.

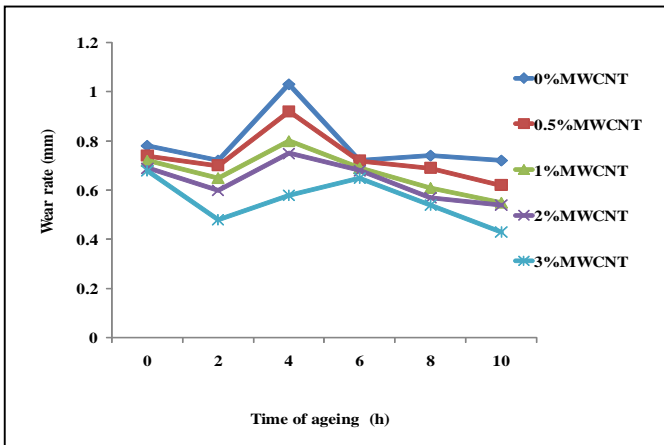


Fig. 11. The variation of wear rate with increasing percentages of MWCNT content in Al6061 for different hours of ageing time under 30 N load for water quenching.

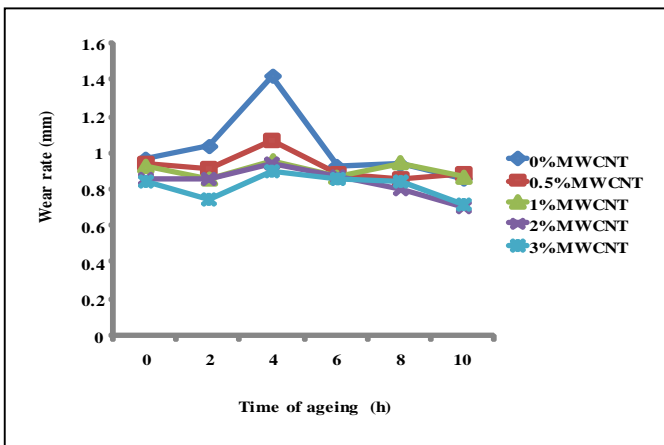


Fig. 12. The variation of ultimate stress for different Al6061-MWCNT composites for different ageing times quenched in water.

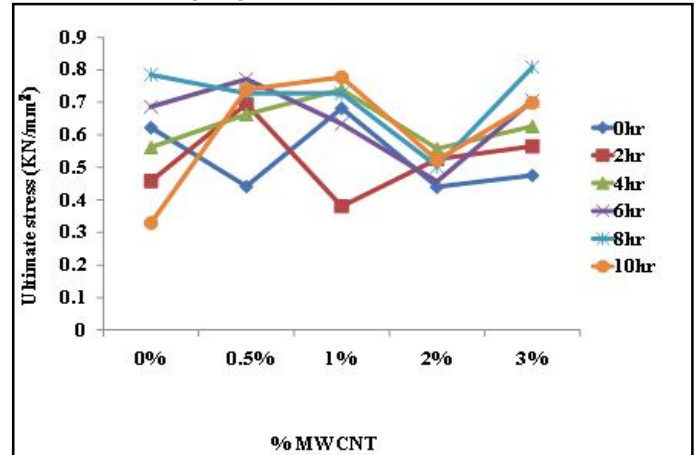
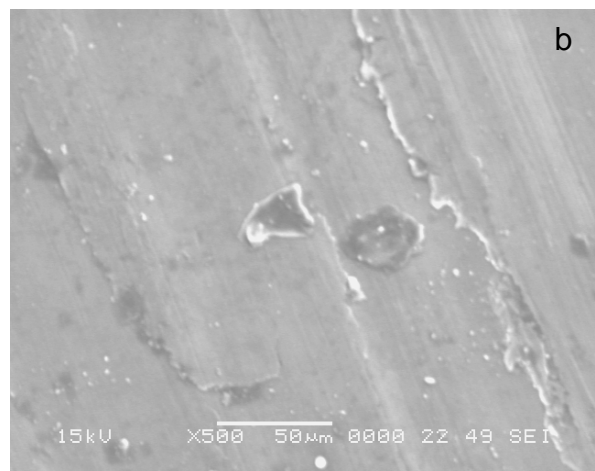
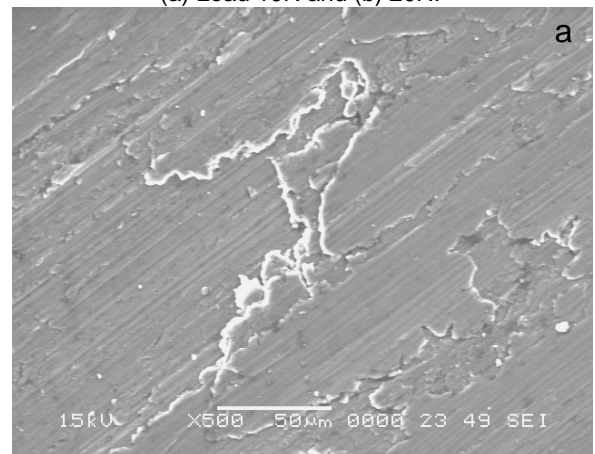


Fig.13. SEM micrographs of the worn surfaces after the wear test under velocity 1 m/s; time 30min; (a) Load 10N and (b) 20N.



It is observed from figure 4 to 11, that the amount of MWCNT reinforcement in the Al6061 matrix alloy have influence on the abrasive wear behavior of Al6061 alloy and its 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.

**Ultimate compression strength:** Compression strength increases with increasing percentage of MWCNT particulates. This may be due to the hardening of the base alloy by MWCNT particulates. Water quench shows ultimate compressive strength increases with increasing MWCNT content. This may be due to the presence of hard MWCNT particulates (Fig. 12).

**SEM micrographs of the worn surface of the composite:** Figure 13a and b shows SEM micrographs of the worn surfaces after the wear test under velocity of 1 m/s, for a run of 30 min. Examination of the worn surfaces of Al6061 alloy-MWCNT composites under the SEM after wear test shows that under the load of 10 N, the worn surface has relatively less ploughing and cutting as shown in figure 13a. However, at the load of 20 N, fractured MWCNT particles are frequently present on the worn surface, as shown in figure 13b.

## Conclusion

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. Macro-hardness of composites increased significantly with increased content of MWCNT. Heat treatment has a significant effect on micro-hardness 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.

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