The Mechanical characteristics of Al7075 Metal Matrix Composites Reinforced with Ni Coated Multiwalled Carbon Nanotubes

[1]Rajesh M, [2]Shivarudraiah, [3]K.V. Sharma, [4]Mahesha C.R.

[1,]Department of Mechanical Engineering, Dr.Ambedkar Institute of Technology, Bangalore, India
[2,3]Department of Mechanical Engineering, UVCE, Bangalore, India
[4]Department of Industrial Engineering and Management, Dr.Ambedkar Institute of Technology, Bangalore, India

Abstract : The latest advancement in the materials are creating an exemplary opportunity to the researchers worldwide. The carbon Nanotubes possess excellent properties to be used as reinforcements for aluminium (Al) based Composites. Efforts have been largely focused on investigating their contribution to the enhancement of the mechanical performance of the composites. In the present study the certain weight percentage of Ni coated Multiwalled Carbon Nanotubes (MWCNT) were reinforced with Al7075 matrix which led to carry of detailed study on tensile, hardness, compression and wear behaviour of the resulting composites. The investigation was carried out with the fabrication of 0%, 2%, 4%, 6% MWCNT reinforced Al7075 composites via stir casting technique tensile strength was increased by 23.13% where as the hardness was found to increase about 32.73% as compared with base material. The wear and friction characteristics of the composite in the extruded conditions were studied by conducting sliding wear test using pin on disc apparatus and observed increased wear rate with the increased sliding distance.

Keywords- Stir casting,MWCNT,wear,ridges

I. Introduction

The quest for the new generation materials is leading the material engineers globally to strive for the high strength, high stiffness low weight materials. With the emergence of a class of functional group like Carbon Nanotubes that possess the capability to fulfil the material strength requirements of the automotive and aerospace industries. It is possible to obtain the tailor made materials to replace the various components which were manufactured using conventional materials. Carbon Nanotubes to be used as the reinforcements with the metal alloys such as Al7075 has to be coated with the metal over its surface to get the better interfacial bonding with the base metal The presence of this nickel layer avoids the diffusion of carbon inside the Al7075 with this it helps to eliminate the possible formation of a carbide layer Al_3C_4. The aluminium carbide will reduce the strength of the Al7075 reinforced with MWCNT composites[1].The size of the MWCNT plays a important role in determining the tensile strength of the Al7075 Composites the smaller and straight MWCNTs will result in the proper diffusion of the carbon nanotubes within the Al7075 alloy[2]. For the dispersion of the MWCNTs in the Al7075 alloy the Stir casting method of moulding the Composites has so far found to be effective resulting in the uniform dispersion [3] provided the optimum stirring speeds has to be maintained. During the higher temperature of the order 700^0C the brittle intermetallic phase formation between the alloy and reinforcements may result which can be completely eliminated by the prior Ni coating over the Surface of MWCNTs [4]. The melt must be free of the impurities and possible intermetallic phase formation with the minor elements such as Fe,Mg,Cr which makes it more potent composites[5].The preheating of the moulds to about 450^0C during the casting will reduce the possible interactions of the minor elements[6].Nickel coating ensures the wetting of the dispersoids with the matrix with reduced interfacial energy and prevents the chemical reaction between the matrix and reinforcements[7].lot of research has been carried out to enumerate the effect of coating of metals over the reinforcements in the Aluminium Matrix Composites and significant results have been reported based on the behavior of the composites. The different volume fractions of the reinforcements like silica, B_4C, Carbon fibres dictates the physical,Tribological,Mechanical properties of the Composites [8-10]. In the present work the Ni coating was confirmed by subjecting the Reinforcements to EDS. Later on the stir casting technique was employed to prepare the Al7075 Composites by adding the MWCNTs as reinforcements in different weight percents and utmost care was taken to achieve the better wetting between the Matrix and reinforcements. Further the Mechanical and Tribological characteristics were focused and discussed.

2. Materials and Methods

The aluminium alloy was Al7075 as the base matrix along with the Ni coated MWCNTs as the reinforcements. The chemical Composition of alloy used is shown in table 1.and the physical properties of the MWCNTs are shown in table 2. Reinforcements were added in weight percents of 2wt%, 4wt%, and 6wt% via stir casting route.

Table 1. Chemical Composition of Al7075 in wt%

Element	% Composition
Fe	0.5
Cu	1.5
Cr	0.2
Si	0.3
Mn	0.3
Mg	2.6
Ti	0.2
Zn	5.8

Al	Bal

Table 2. Properties of Muliwalled Carbon nanotubes

Properties	Values
Diameter	20nm
Length	20µm
Purity	>98%
Density	0.2g/cm3
Metal particles	<1%

2.1 Ni Coating of the MWCNTs

In the beginning the MWCNTs that was procured are initially cleaned with acetone solution for 10 minutes, so that the MWCNTs maintain the proper roughness on the surfaces and are then placed on the hot oven and preheated to 200^0C, thus the acetone solution is evaporated and fibers are dried resulting MWCNTs were subjected to the electroless nickel coating following sensitization, activation and metallization process using $NiSO_4$ solution in the presence of sodium hypophosphate then the resulting MWCNTs were dried at around 450^0C and preserved in the desiccators for the fabrication phase.

2.2Fabrication of Composites

The Al7075 alloy and Ni coated MWCNTs and the mould where the molten metal is to be poured is placed in the muffle furnace and preheated for about 4500 C then degassing agent asbury tablets are immersed and plunged to the bottom of the crucible to remove all impurities. The Al7075 alloy are maintained and the temperature is gradually increased to the melting point till it is transferred to the Al7075 melt. For the Al7075 melt at 7000C the The preheated weighed MWCNT reinforcements are poured into the crucible for mixture with the Al7075 melt in weight percents of 2wt%,4wt% and 6wt% .Stirring with the stirrer made up of stainless steel coated with Cr and attached with three fixed blades is continued till the matrix and the reinforcement interacts between each other and promoted wettability. Then the melt with the crucible is removed from the heater and poured into the heated mould. After the melt is poured, it is then left out for cooling for around 3 hours at room temperature and the mould specimen is separated

3. Mechanical Testing

After the completion of the casting process the moulds and the specimens were separated and the cylindrical composites were prepared to evaluate the mechanical properties of Al7075 reinforced with MWCNT composites

3.1 Sample preparation

The tensile and compression testing was carried out using the UTM (TUE 600 C) machine. The testing samples were machined as per the ASTM E8M standards and for the wear test the cylindrical round specimens of the dimensions 10 mm diameter and 30 mm length was prepared as per the G99 standards. Between the each tests the composite specimens are cleaned thoroughly and its surfaces are prepared by polishing specimens with the 300 grade emery paper so that the tests are conducted in the effective manner.

3.2 Design of experiments

The wear test was carried out using pin on disk machine the wear behavior was studied as per the ASTM G99 standards the specimens was prepared with the dimensions 10mm diameter and 30mm length. Initially all the specimens were cleaned using acetone solution and polished with 250 grade emery paper to obtain a clear surface finish. The parameters chosen to conduct the wear test was the load(L), Sliding distance(D) and Speed(S) and the values for which the test was conducted is listed out in the table 3. The weight loss was measured using digital balance corrected upto 3 decimal places. Taguchi technique was employed and L9 orthogonal array was selected to vary the test parameters using minitab. The wear rate was calculated by weighing the samples during each trial and recording the volume loss.

Wear rate (W_R)= Wear Volume Loss (V_L) / Sliding Distance (D_s) (1)

Specific Wear rate (k_i) = V_L / F. D_s mm^3/N-m (2)

Wear resistance (W_r) = 1/Wear rate m/ mm^3 (3)

Table 3. wear test parameters

Load (N)	Distance (km)	Speed (m/s)
0	0.5	0.5
10	1	1
20	1.5	1.5
30	2	2

4. Results and Discussions

After the casting of Al7075 reinforced with MWCNTs composites initially the specimens were subjected to the tensile test which was carried out using the UTM machine as per the ASTM Standards the test results are tabulated in the table 4.

Table 4. Ultimate Tensile Strength and percentage variation of Al7075 reinforced with MWCNT

Sl No.	wt% of CNTs	Ultimate Tensile Strength (MPa)	Percentage Variation (%)

1	0	170.35	0
2	2	186.46	8.64
3	4	197.68	13.83
4	6	210.64	19.13

Figure 1. Shows the increased trend with the addition of MWCNT reinforcements the ultimate tensile strength was found to increase highest of about 23.13% for 6wt% of MWCNT. The density of MWCNTs are low compared to the base material AL7075 which results in the uniform dispersion of nanotubes within the matrix as shown in the SEM image in Fig.7,8 The improved material strain rate of the composites along with the ductility has enabled the composite to withstand the higher loads.

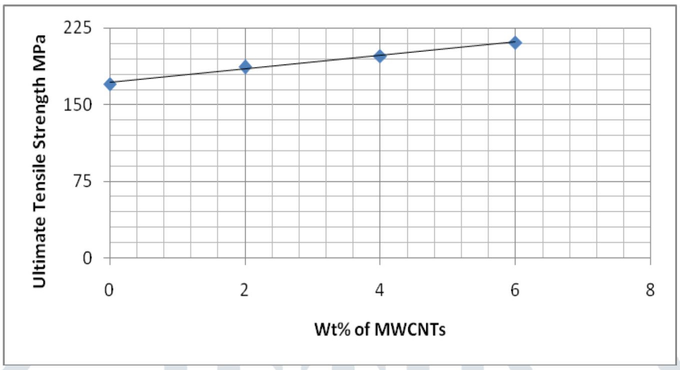

Figure 1. Ultimate Tensile Strength vs Al7075 reinforced with MWCNT

The Brinell hardness test of the composites reveals that simultaneous improvement in the hardness and compressive strength of the composites table 5. Shows the hardness test results.

Table 5. Brinell Hardness No. Vs wt% of MWCNT

Sl No.	wt% of CNTs	BHN
1	0	74
2	2	88
3	4	104
4	6	110

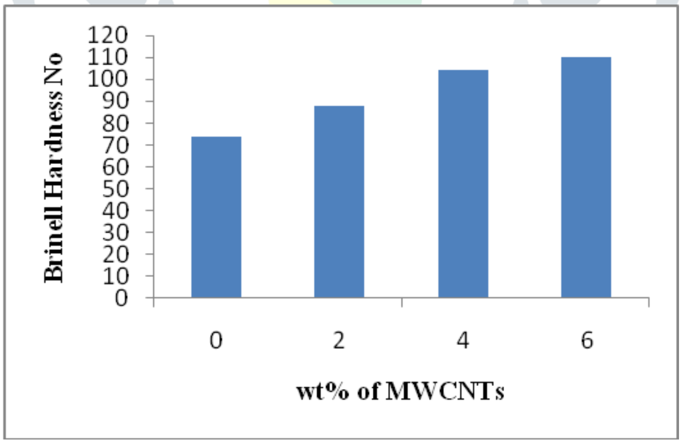

Figure 2. Brinell Hardness No of Al7075 composites vs wt% of MWCNTs

The Ni coated Carbon nanotubes occupies the vacant sites in the Al7075 crystalline lattice the stir casting method involves in the uniform dispersion of the reinforcements resulting in the strong intermetallic atomic bonding causing the increase in the hardness of the composites results shows the 32.73% increase in hardness which can be observed for 6wt% of MWCNTs in Fig. 2. The compressive strength of the composites was also increased sharply almost 45% with the increase in the wt% of MWCNTs which is depicted from Fig. 3

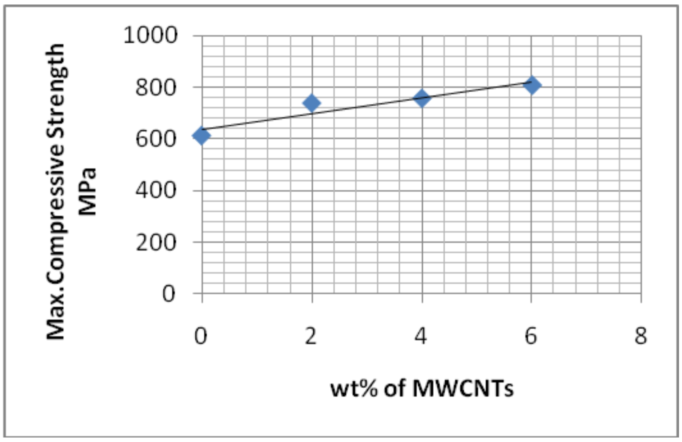

Figure 3. Ultimate Comprssive Strength vs wt% of MWCNTs

The wear test was conducted as per ASTM G99 standards using Pin on disk equipment the load and speed was kept constant and the sliding distance was varied after each trial the specimen was weighed using digital balance. The wear characteristics keeping load 10N and speed 1m/s constant the wear loss in mm^3/m are given in the table 5.

Table 5. wear loss in mm^3 keeping Load = 10N and Speed = 1 m/s constant

wt% MWCNT	Sliding Distance(km)			
	0.5	1	1.5	2
0	0.0116	0.0167	0.0254	0.0279
2	0.0108	0.0193	0.0197	0.0198
4	0.0102	0.0177	0.0181	0.0188
6	0.0101	0. 159	0.0174	0.0176

The Fig. 4 shows the increase in the wear rate as the sliding distance increases from 0.5km to 2km while the wear rate reduces with the increase in the wt% of MWCNT composition.

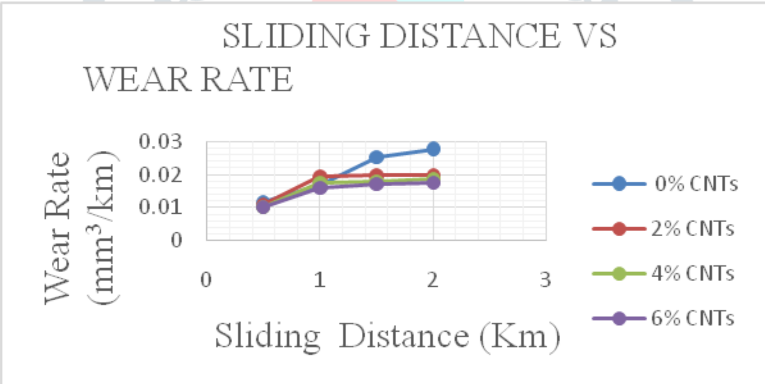

Figure 4. Sliding Distance vs wear rate for Constant Load = 10N and Speed = 1m/s

Table 6. shows the wear rate for the load 20N and speed 1.5 m/s constants here it is evident that as the wt% of the reinforcements is increasing the wear rate reduces Fig. 5

Table 6. wear loss in mm^3 keeping Load = 20N and Speed = 1.5 m/s constant

wt% MWCNT	Sliding Distance(km)			
	0.5	1	1.5	2
0	0.0129	0.0276	0.0398	0.0434
2	0.0111	0.0223	0.0266	0.3610
4	0.0102	0.0207	0.0219	0.3872
6	0.0055	0. 0094	0.0109	0.0275

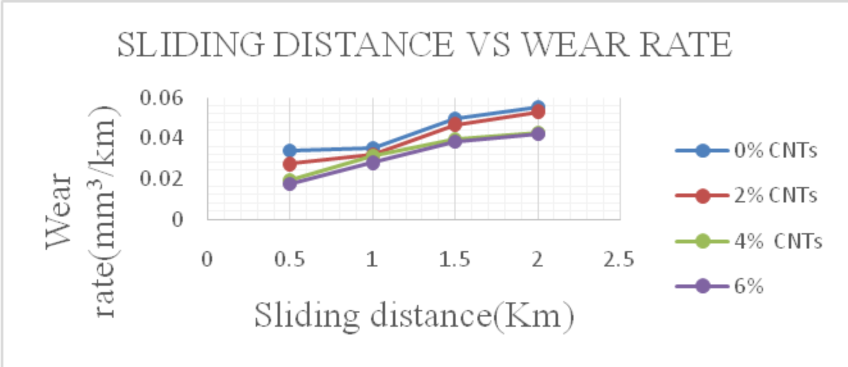

Figure 5. Sliding Distance vs wear rate for Constant Load = 20N and Speed = 1.5 m/s

Table 7. shows the wear behaviour for the load 30N and speed 2m/s here also the low wear rates can be attributed to the addition of the carbon nanotubes the composite has become harder. The uniform dispersion of the reinforcements increases the hardness even more. With the increase in the sliding distance due to the density variation the concentration of the nanotubes also becomes dim causing the slight reduction in the wear rates as shown in Fig. 7

Table 7. wear loss in mm^3 keeping Load = 30N and Speed = 2 m/s constant

wt% MWCNT	Sliding Distance(km)			
	0.5	1	1.5	2
0	0.0346	0.0397	0.0441	0.0632
2	0.0342	0.0394	0.0399	0.0543
4	0.0362	0.0376	0.0397	0.0441
6	0.0309	0.0368	0.0384	0.0562

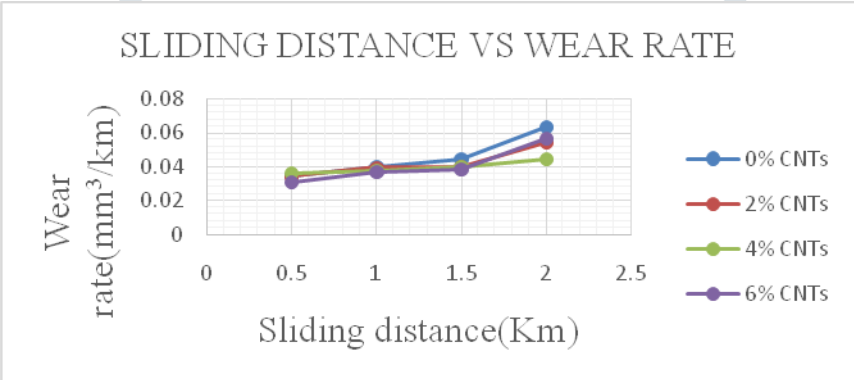

Figure 6. Sliding Distance vs wear rate for Constant Load = 30N and Speed = 2 m/s

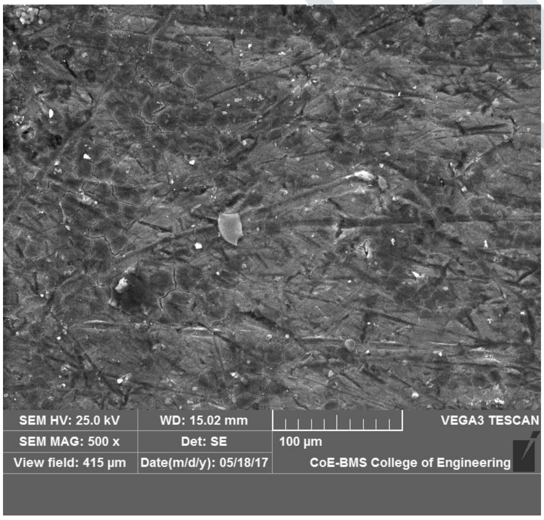

Fig. 7: SEM image of worn surface of Al7075 reinforced with 4wt% MWCNT

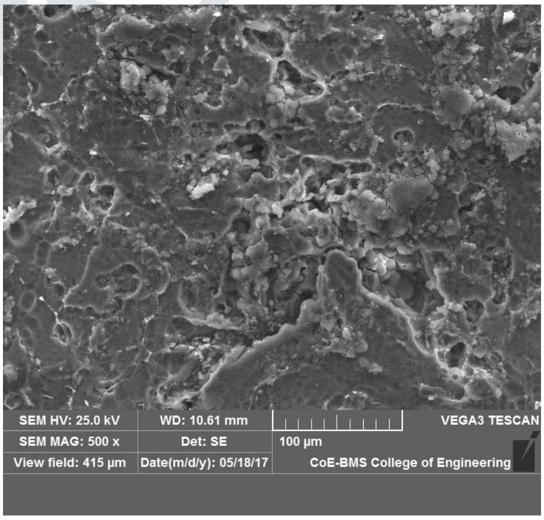

Fig. 8: SEM image of worn surface of Al7075 reinforced with 6wt% MWCNT

From the SEM image Fig. 7 it is clear that the sliding of the pin has caused deep ploughing into the composite specimen giving rise to ridges and delamination this phenomenon can be attributed to the material loss due to wear. Fig. 8 shows the presence of pores and micro cracks possibly because of the deterioration of the material with the increased load and sliding distance the worn surface depicts the mechanism of wear was highly dominated by the sharp peaks and deep valleys along the sliding direction in the crystallographic structure.

5. Conclusions

The present work was carried out by conducting stir casting and preparing Al7075 reinforced with MWCNTs composites for the 2wt%, 4wt%, 6wt% . later the mechanical properties were evaluated by subjecting the composites to tensile, hardness and compression tests. The results revealed that the uniform dispersion of the reinforcements within the matrix Al7075 has improved the ultimate tensile strength by 23.13% highest for the 6wt% MWCNT inclusion and the hardness was increased about 32.73% in comparison with base material. the compression strength was also improved almost 45%.the wear characteristics reveals that the wear rate was considerably lowered with the addition of the MWCNTs and as the sliding distance increased the wear was also found to be increased. The microstructure analysis confirms the delamination mechanism was the dominating factor for the wear of the composites.

6. References

[1] Silvain J.F, J. M. Heintz and M. Lahaye, Interface analysis in Al and Al alloys/Ni/Carbon composites, Journal of Materials Science, Vol 35, 2000, pp 961 965.

[2] Esawi et.al. "Fabrication and properties of dispersed Carbon Nanotube-Aluminium Composites" Materials Science and Engineering a 508(2009) pp.167-173.

[3] Srinivasan R, P Vijaykumar, Dr H. K. Shivanand."Studies on Mechanical Characteristics of Carbon Nanotubes(CNT) Reinforced with 6061 Aluminium Metal Matrix Composites coated with Nickel"International Journal of Innovative Research in Science, Engineering and Technology, Vol 5, Issue 8, August 2016. ISSN:2319-8753

[4] Nithin Kumar, H.C. Chittappa, S. Ezhil Vannan" Development of Aluminium – Nickel Coated short Carbon fiber Metal Matrix Composites" Material today Proceedings 5 (2018) 11336-11345

[5] Hansang kwon, Mehdi Estili, Takamichi,Akira Kawasaki et. al. "Discussion on the Mechanical Behavior of Carbon Nanotube/C60 Composite based on Observation of Interfacial Structure" Materials Transactions,JIM,Vol 39,No 5(1998) pp. 578-581.

[6] Satnam Singh, **Manish** Garg, N.K. Batra "Analysis Of Dry Sliding Behavior Of Al2o3/B4c/Gr Aluminium Alloy Metal Matrix Hybrid Composite Using Taguchi Methodology" 10.1080/10402004.2015.1015757

[7] W. S. Lee, W. C. Sue and C. F. Lin, "The effects of temperature and strain rate on the properties of carbon-fiber-reinforced 7075 aluminium alloy metal-matrix composite, Composites Science and Technology, Vol 60, 2000, pp 1975-1983.

[8] Nithin Kumar et. al. " Corrosion Behaviour of Nickel Coated Short Carbon Fiber Reinforced Al Metal Matrix Composites" International Journal of Theoretical and applied Mechanics. ISSN 0973-6085 Vol 2 No. 3 (2017) pages 659-669

[9] Suleyman Bas turk, Haydar Uyanik, Zafer Kazanci, "An analytical model forPredicting the deflection of laminated basalt composite plates under dynamic loads", Composite Structures, Vol. 116, 2014, pp. 273–285.

[10] Zong Y, Derby B,"Microstructure and fracture behaviour of SiCp/Al -2618 metal matrix composite", Journal de Physique, Vol. IV, 1993, pp. 1861-1866.

[11] Sayuti M, Sulaiman T.R, Vijayaram B.T, Baharuddin H.T, Arifin M.K.A, "Manufacturing and Properties of Quartz (SiO2) Particulate Reinforced Al-11.8% Si Matrix Composites", Vol. 10, 2012, pp. 5772-5782.

[12] T Gunasekaran1, M Akilan, S S Anandbabu, N Deeapkkumar, D Arunprasath" The Effect of Various Reinforcements on Aluminium Alloy (Al7075) – A Review" ICSSCCET.2016.181

[13] Muhammad Mansoor, Muhammad Shahid "Carbon nanotube-reinforced aluminum composite produced byinduction melting" Journal of Applied Research and Technology,May 2016

[14] M. Asif, K. Chandra, P.S. Mishra, "Development of Aluminium Based Hybrid Metal Matrix Composites for Heavy Duty Applications", Journal of Minerals & Materials Characterization & Engineering, 2011,Vol.10, No.14,pp.1337-1344.