



FRICITION COEFFICIENT OF CARBON NANOTUBE REINFORCED ALUMINIUM NANO-COMPOSITE

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ABSTRACT

The frictional behaviour of three different nano-composites such as 1.5 wt %, 2.0 wt % and 2.5 wt % CNT–Al nano-composite materials developed by powder metallurgy process has been studied with pin-on-disc tribometer, sliding against AISI52100 steel disc. The tribological properties of pure aluminium and carbon nanotube reinforced aluminium nano-composite were investigated and compared in this current study. Experiments were conducted using different sliding velocities of 0.5, 0.65 and 0.8 m/s and a normal load of 5, 7.5 and 10 N. Variations of coefficient of friction with the duration of rubbing at different normal loads and sliding velocities are investigated. It was revealed from the results that, coefficient of friction varies with the duration of rubbing, normal load and sliding velocities. It was clearly observed that, coefficient of friction increases for a certain duration of rubbing and after that it remains constant for the rest of the experimental time. Furthermore, the result shows that, coefficient of friction decreases with the increase in normal loads for aluminium while for the nano material it decreases slightly for certain operating condition and remains constant in some cases. It is also observed that coefficient of friction decreased with the increased in sliding velocities for aluminium and almost remain the same for the nano material. It was further confirmed that, the developed nano material has a very high resistance to friction with low and stable coefficient of friction which is within the range of 0.0050 - 0.01835. Further work has been recommended to be conducted on the developed material and check on the possibility of using it as a cladding material in the nuclear reactor chamber.

Keywords: Coefficient of friction, self-lubrication, carbon nanotube, aluminium metal matrix composite, powder metallurgy.

INTRODUCTION

The demand for lightweight, energy saving materials in transportation industries is rising rapidly. It motivated a rapid growing activity to develop specific composite and reliable processing techniques. Metal matrix composite (MMC) (Nautiyal *et al.*, 1983) reinforced with carbon nanotube are recognized for their higher specific modulus, strength, and wear and frictional resistance, as compared with other conventional metallic materials. Applications in which materials are subjected to mechanical wear and friction include, brake disc, piston, bearings surface etc. The understanding of the wear, friction and lubrication behaviour of materials, lubricants and coatings in a variety of test conditions has become increasingly important in the recent years. With the invention of new applications and technologies like automotive, advanced lubricants, new materials and composites, traditional tribometers and measurements technologies are no longer to be enough for all applications. Today many researchers had introduced advance materials as a substitute to the traditionally used materials as these modified materials are light weight and excellent in wear and friction resistance, as well as improved life span. For an instance, Nautiyal *et al.* (1983) observed that the factors responsible for wear of a piston ring sliding against cast iron combustion chamber were its surface

temperature, peak combustion pressure, total energy of the wearing surfaces and other physical properties of the material under sliding. As such Dahm *et al.* (2003) proposed to replace the conventional piston rings with ceramic matrix nano composite piston rings as the latter had smooth wear (i.e. micro scale wear) which contributed in low wear rates during the test. Hence, scientific ideology and calculating methods of creating new materials / composites and estimation of its wear resistance of friction nodes as well as physical simulation of friction and wear processes on a small-sized laboratory test machine need to be carried out experimentally before a future material/composite is commercially introduced in the market Dahm *et al.* (2003) and Nirmal *et al.* (2011). Before the advent of the proposed composite material, a suitable type of wear test equipment should be used together with a suitable parameters selected which reflect the real time application of the composite. Examples of this parameters are testing techniques, type of counter face used against the test samples, sliding velocities, sliding distances, applied loads, contact conditions and orientations of the test specimen with respect to the sliding direction of the counter face. Based on this idea the present authors proposed CNT-Al nano-composite material to be used for brake disc application and to be tested before introduce in to the commercial sector. Chowdhury *et al.*

(2007-2009) reported that the frictional coefficient of different metals and alloys showed various behaviour under varying operating conditions. In spite of this investigations, the effect of normal load and sliding velocity on friction coefficient of different materials especially alloys are yet to be understood clearly. Chowdhury *et al.* (2009) study the effect of normal load and sliding velocity on friction behaviour of different material combination basically copper and brass. The drawback with this studies are, they focus mainly for metals and alloy especially copper and the properties for alloys is not the same with composite materials. Recently the utilisation of composite materials especially nano-composite material is increasing rapidly. Based on this the present authors realised the need to study the frictional behaviour of metal matrix nano-composite at various operating condition. The main aim of this study is to conduct wear and friction test using pin-on-disc machine and study the effect of normal load and sliding velocity on friction coefficient of CNT-Al nano-composite. Wear analysis will be presented in the next paper title Wear analysis and characterization of carbon nanotube reinforced aluminium nano-composite, with hope that the result will contribute for mechanical and tribological applications.

EXPERIMENTAL DETAILS

Materials

The composite were produced using pure aluminium (99.7% Al), with particle size of 78 μm which has nearly spherical shape with some satellite sub-particles obtained from Innovative Pultrusion Sdn Bhd, a local supplier for the aluminium powder in Malaysia was used as a matrix material. The composition of CNT-Al nano-composite is presented in Table 1.

The multi walled carbon nano tubes (MWCNTs) with a nominal diameter of 10 nm, length of 5-15 μm , and surface

area of 230-280 m^2g^{-1} was also obtained from the same supplier in Malaysia and used as a reinforcement.

Fabrication and composites microstructure

The composite was made based on the percentage composition of CNT in to the Al powder. High energy planetary ball mill machine with 250 ml stainless steel jar, steel balls of 10mm diameter was used for the fabrication of CNT-Al nano-composite powder, and to ensure the effective dispersion of CNT in to the Al matrix. The jar was filled with argon gas and the ball mill operations was performed using planetary mill (FRITSCH pulverisette 5) at constant speed of 300 rpm for three different milling time of 1, 2 and 3 hours. Samples were extruded from each batch at regular interval of 1 hour for analysis using a field emission scanning electron microscope (FESEM) in order to investigate the dispersion of the CNTs in the Al matrix and also to analyze the nano-composite particle morphology and shape. Each composition was compacted using cold unidirectional pressing machine at the pressure of 48 MPa for each sample. The mould for the sample compaction was 10 x 10 x 20 mm to make the standard size for pin-on-disc machine sample. The samples were sintered using hot isostatic press (HIP) machine (HP630) at 500°C and the argon gas was supplied at the pressure of 17 MPa for 60 min to control the atmosphere in the process. After sintering the sample to strengthen the intermetallic bond the pin-on-disc experiment commenced.

Friction and wear test (dry contact condition)

Pin-on-disc machine was built based on ASTM G99 standard. It has the same working principle with the commonly used pin on ring. However, the test specimen with size of 10 mm x 10 mm x 20 mm subjected to the counter face exhibits an unvarying contact area all through the test. The test setup is shown in Figure 1 below.

Table 1: Mixing composition of CNT-Al nanocomposite

Sample	Composition of nanocomposite (wt %)	Abbreviation
1	Al (99) + CNT (1.0) + Ethanol (1.0 ml)	1 wt %
2	Al (98.5) + CNT (1.5) + Ethanol (1.0 ml)	1.5 wt %
3	Al (98.0) + CNT (2.0) + Ethanol (0.85 ml)	2.0 wt %
4	Al (97.5) + CNT (2.5) + Ethanol (0.85)	2.5 wt %

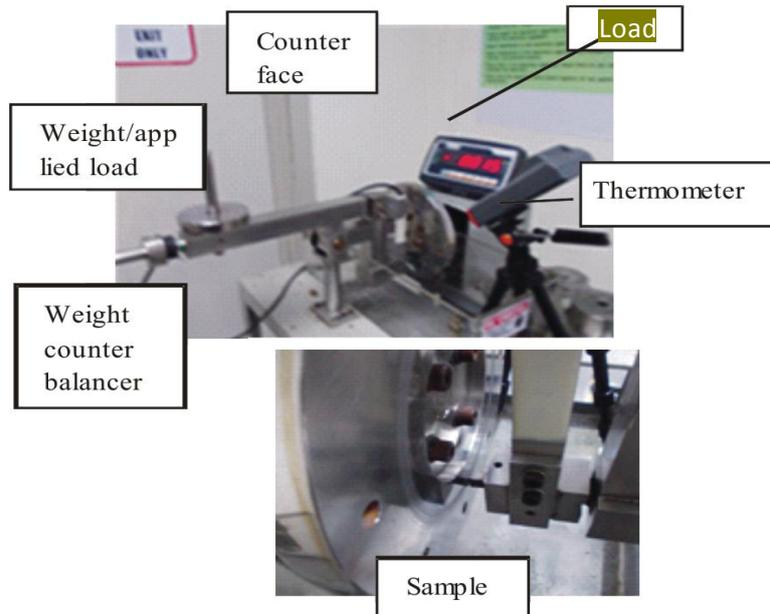


Figure 1: Pin-on-disc experimental setup

Pin-on-disc experimental setup

The test specimen is set perpendicular and horizontal to the counter face. A load cell is directly included in the load lever of the machine to capture frictional forces during the test. A counter weight balancer is incorporated at the end of machine's load lever to balance the lever arm before starting the testing. This is step has to be done when no load is applied. The counter face material depends on the nature of the test; it can be of various types (i.e. metal, cast iron, titanium, aluminium, stainless steel, etc). Commonly, this test is simulated for applications such as sliding wear of various materials where constant contact area of interest.

When the machine and sample setting is done, then the experiment started for a period of 12 min. The detail experimental conditions are presented in Table 2.

RESULT AND DISCUSSION

CNT-Al Morphology

Figure 2 presents the images of CNT and aluminium as it received from the supplier. Field emission scanning electron microscope (FESEM) at higher magnification was used to observe the morphology of CNT and scanning electron microscope (SEM) was used for Aluminium.

Table 2: Experimental conditions for wear and friction test

Operating conditions	Values
Duration of rubbing (min)	12
Wheel speed (rpm)	42, 54 and 66
Sliding speed (m/s)	0.50, 0.65 and 0.8
Frequency (Hz)	0.7, 0.9 and 1.1
Normal load (N)	5.0, 7.5 and 10
Materials:	Pure aluminium and CNT-Al nanocomposite
(i) Pin	AISI 4340 hardened steel (Hardness value, 650/700 Brinell hardness)
(ii) Disc	

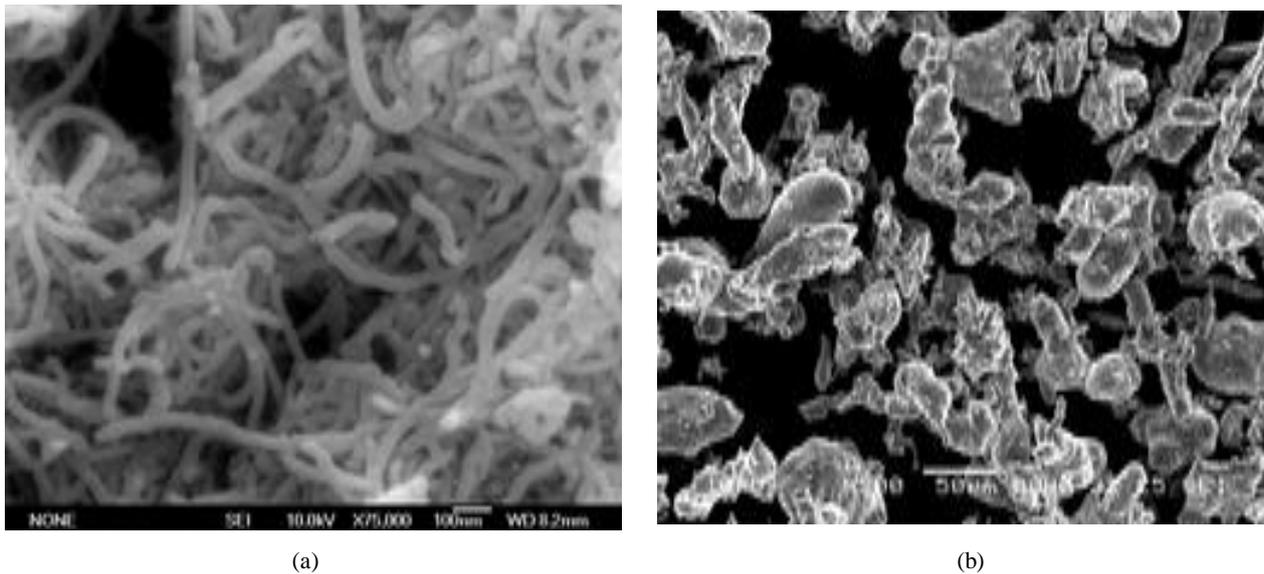


Figure 2: As-received image of (a) CNT and (b) Aluminium powder

Figure 3 present the field emission scanning electron microscope (FESEM) micrograph of CNT-Al nanocomposite

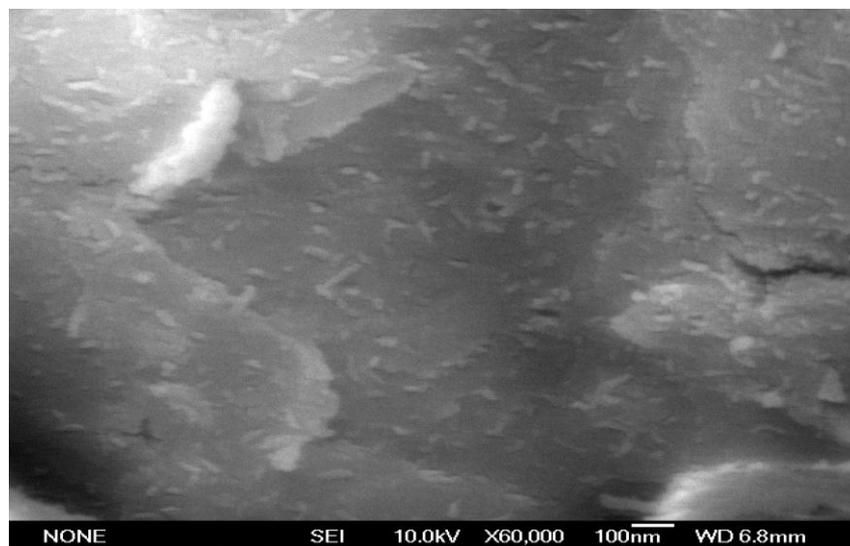


Figure 3: FESEM micrograph of CNT-Al nano-composite showing a uniform and homogeneous dispersion of CNT in to Al matrix at high magnification

The figure is showing a uniform and homogeneous dispersion of CNT in to Al matrix after ball milling operation to develop a carbon nanotube reinforced aluminium nanocomposite. It is observed from Figure 3 that, the dispersion of CNT as reinforcement is uniform and homogeneous in Al matrix. The achievement can be as a result of the use of appropriate quantity of ethanol as a process control agent and preliminary mixing of CNT and Al via manual hand shake before milling operation. The

homogeneity of CNT in to the matrix ensures the improvement of the new developed material.

Coefficient of friction of the developed nano-composite material (CNT-Al)

The effects of duration of rubbing on friction coefficient of CNT-Al nano-composite are examined and compared with pure Al. Figure 5 shows the variation of coefficient of friction with the time taken during rubbing the materials (CNT-Al and Al) on the counter face at varying normal load at 0.50 m/s sliding velocity throughout the experiment.

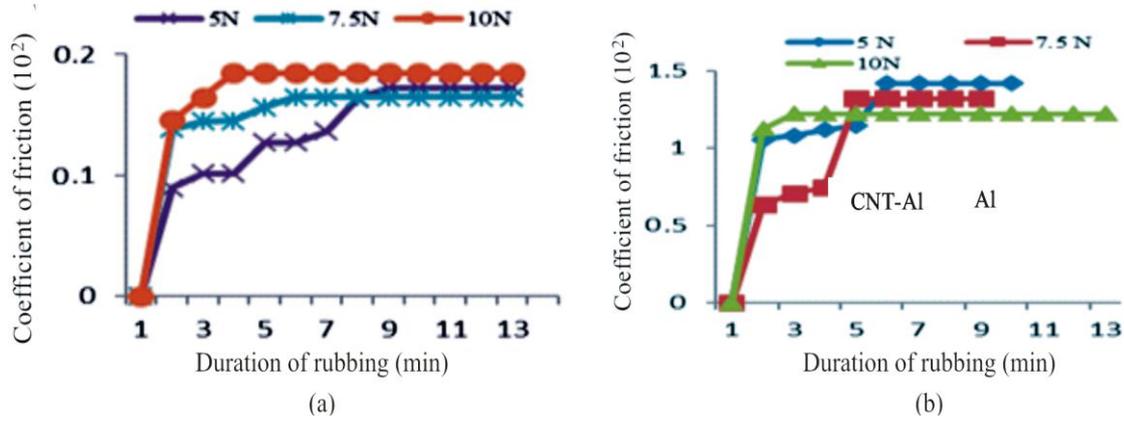


Figure 4: Variation of coefficient of friction with respect duration of rubbing and at different normal loads with fixed sliding velocity of 0.50 m/s. (a) CNT-Al and (b) Al

The figure above was the result obtained in Table 3 which presents Coefficient of friction at three different normal loads at 0.50 m/s sliding velocity for CNT-Al nano-composite.

Six curves were drawn in Figure 4, the first three at (a) represent the frictional coefficient at different rubbing time for CNT-Al nano-composite, and those three at (b) represent

that of pure Al. From the first curve drawn for normal load of 5 N, it is observed that the value of coefficient of friction is 0.00900 at the first minute and then increased slightly with the increase in the duration of rubbing to reach the maximum value of 0.01727 over a duration of 8 minutes from where it remains constant until the last minute of the experiment.

Table 3: Coefficient of friction at three different normal loads at 0.50 m/s sliding velocity for CNT-Al nano-composite

Materials	Al			CNT-Al		
	5	7.5	10	5	7.5	10
Normal loads (N)	5	7.5	10	5	7.5	10
Time (min)	Coefficient of friction					
1	0.10545	0.06319	0.11240	0.00900	0.01384	0.01460
2	0.10818	0.07083	0.12210	0.01018	0.01450	0.01650
3	0.11182	0.07431	0.12210	0.01018	0.01455	0.01850
4	0.11455	0.09583	0.12210	0.01272	0.01565	0.01850
5	0.12091	0.11458	0.12210	0.01272	0.01650	0.01850
6		0.13194	0.12210	0.01364	0.01650	0.01850
7	0.12182	0.13194	0.12210	0.01636	0.01650	0.01850
8	0.14182	0.13194	0.12210	0.01727	0.01650	0.01850
9	0.14182	0.13194	0.12210	0.01727	0.01650	0.01850
10	0.14182	0.13194	0.12210	0.01727	0.01650	0.01850
11	0.14182	0.13194	0.12210	0.01727	0.01650	0.01850
12	0.14182	0.13194	0.12210	0.01727	0.01500	0.01850

The friction coefficient is low at the initial minutes of the experiment, this is due to the presence of CNT in to the composite, and CNT act as a lubricant and form a layer which can prevent the direct contact of the two mating surfaces and reduce the friction which at the same time increases the frictional resistance of the material. As the time of rubbing increase the heat is generated and absorbed by the material which leads to little breakage of the layer and that increases the contact between the materials. At the same time the friction force increases with the increase in the duration of rubbing due to the increase in surface roughening of the disc during rubbing which reach a steady stage together with other parameters hence the friction coefficient remains same for the rest of experimental time. The second and third curves drawn for normal load of 7.5 and 10 N respectively shows similar trends with the first curve. It was revealed from these curves that, the value for each curve to reach constant varies with the normal load. The higher the normal load the smaller the time for the curve to reach the steady state. It was observed that for 5, 7.5 and 10 N the value to reach the steady state for each one is 8, 5 and 3 minute respectively. While for pure aluminium all the curves show similar trends with that of CNT-Al but with higher value of friction coefficient. At the initial stage the coefficient of friction is 0.010545 which increases with the duration of rubbing to a value of 0.014182 over the duration time of 7 minutes and remains constant until the end of the experiment. Similar observation was made for the rest of the two curves as the load is increasing the steady state time reduce. May be is as a result of the oxidation nature of aluminium in its pure form especially in powder before compaction. Aluminium powder in its pure form oxidizes readily in air to form an oxide layer which prevents it from further oxidation. The layer for oxides of metal deposited on the aluminium can separate the two materials and prevent the rubbing contact between the surfaces at the initial stage of the experiment. This layer can now break due to the heat

generated during the rubbing and now the actual surface of the material is getting more contact which result in high value of coefficient of friction that can leads to poor friction resistance compared to the new developed material (CNT-Al). Table 4 and 5 presented the same results at different sliding velocities.

Figure 7 (a), (b) and (c) presents the difference for the range of the variation of coefficient of friction with normal load for CNT-Al nano-composite and Al. The curve is plotted mainly to observe the difference of coefficient of friction at a steady state point at varying load and sliding velocity. It is observed that the coefficient of friction varies from 0.14182 to 0.1221, 0.185 to 0.1727 at 0.5 m/s, 0.16245 to 0.09950, 0.01835 to 0.01200 at 0.65 m/s and 0.16270 to 0.13500, 0.01755 to 0.00833 at 0.8 m/s sliding velocity with the variation of normal load from 5 to 10 N for pure Al and CNT-Al nano-composite respectively. These results also show that coefficient of friction decreases with the increase in normal load. Combine effect of sliding speeds and loads on coefficient of friction of 1.5 wt % CNT-Al nanocomposite and pure Al. Wear debris of pure Al and increased surface roughening can be responsible for the decrease in friction with the increase in normal load (T. Oktay *et al.*, 1992). Jin-liong *et al.* (2007) obtained similar findings on frictional behaviour of CNT-Al nanocomposite. The CNT-Al showed very good lubricating behaviour, ability to absorb heat and higher strength which can prevent the material from deforming as a result of the compressive force applied during rubbing. It can be concluded that, coefficient of friction of CNT-Al nanocomposite decreases with the increasing of normal load and increases with the increasing sliding velocity for different normal loads of 5, 7.5 and 10 N and CNT acts as a solid lubricant which also showed improved mechanical property, wear and frictional resistance.

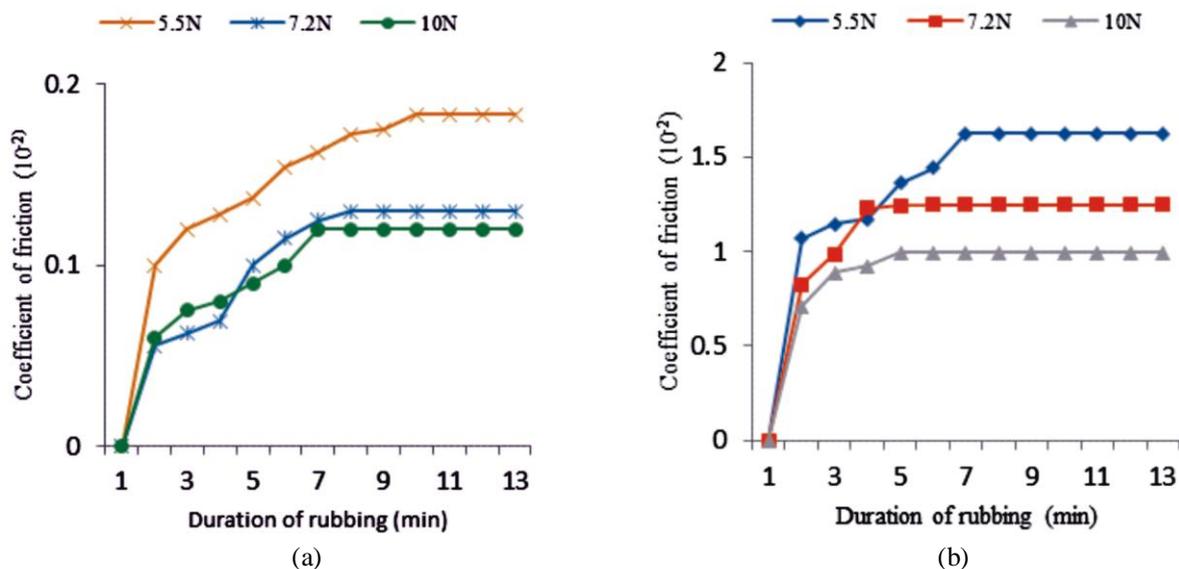


Figure 5: Variation of coefficient of friction with the respect to duration of rubbing and at different normal loads with fixed sliding velocity of 0.65 m/s. (a) CNT-Al and (b) Al

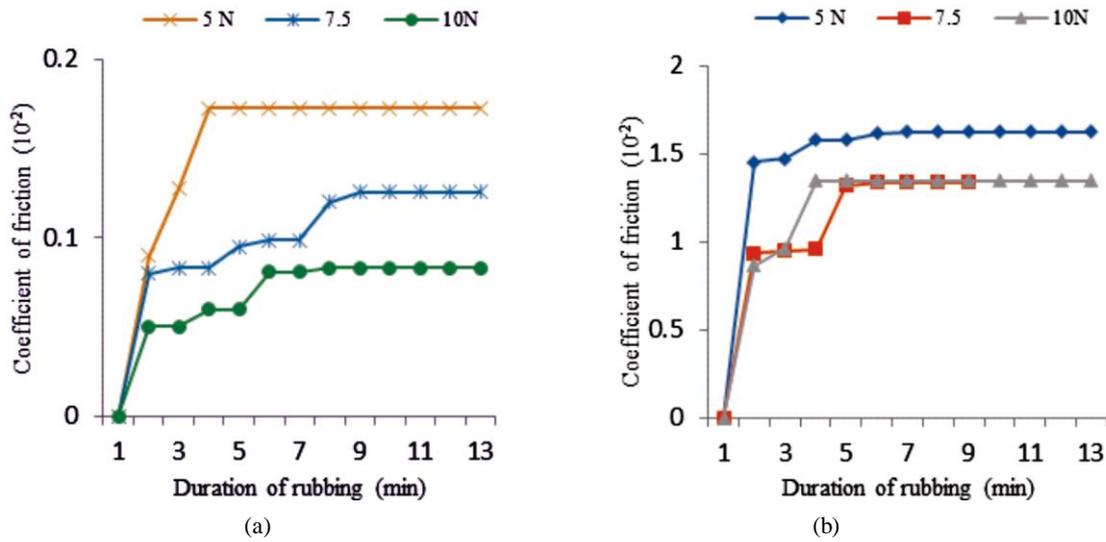


Figure 6: Variation of coefficient of friction with respect to duration of rubbing and at different normal loads with fixed sliding velocity of at 0.8 m/s. (a) CNT-Al and (b) Al

Table 4: Coefficient of friction at different normal loads for Al and CNT-Al nano-composite (sliding velocity 0.65 m/s)

Materials	Al			CNT-Al		
Normal loads (N)	5	7.5	10	5	7.5	10
Time (min)	Coefficient of friction					
1	0.10727	0.08264	0.07100	0.01000	0.00556	0.00600
2	0.11455	0.09861	0.08900	0.1200	0.00625	0.00750
3	0.11727	0.12322	0.09250	0.01282	0.00694	0.00800
4	0.13636	0.12451	0.09950	0.01373	0.01000	0.00900
5	0.11443	0.12500	0.09950	0.01545	0.01150	0.01000
6	0.16245	0.12500	0.09950	0.01627	0.01250	0.01200
7	0.16245	0.12500	0.09950	0.01727	0.01300	0.01200
8	0.16245	0.12500	0.09950	0.01835	0.01300	0.01200
9	0.16245	0.12500	0.09950	0.01835	0.01300	0.01200
10	0.16245	0.12500	0.09950	0.01835	0.01300	0.01200
11	0.16245	0.12500	0.09950	0.01835	0.01300	0.01200
12	0.16245	0.12500	0.09950	0.01835	0.01300	0.01200

Table 5: Coefficient of friction at different normal loads for Al and CNT-Al nano-composite (sliding velocity 0.8 m/s)

Materials	Al			CNT-Al		
	5.5	7.2	10	5.5	7.2	10
Normal loads (N)	5.5	7.2	10	5.5	7.2	10
Time (min)	Coefficient of friction					
1	0.14545	0.09375	0.08650	0.00900		0.00500
2	0.14727	0.09514	0.09650	0.01272	0.00800 0.00833	0.00500
3	0.15818	0.09583	0.13500	0.01700	0.00833	0.00600
4	0.15818	0.13194	0.13500	0.01727	0.00950	0.00600
5	0.16182	0.13403	0.13500	0.01727	0.00985	0.00810
6	0.16273	0.13403	0.13500	0.01750	0.00985	0.00810
7		0.13403	0.13500	0.01750	0.01200	0.00833
8	0.16273 0.16273	0.13403	0.13500	0.01750	0.01255	0.00833
9	0.16273	0.13403	0.13500	0.01755	0.01255	0.00833
10	0.16273	0.13403	0.13500	0.01755	0.01255	0.00833
11	0.16273	0.13403	0.13500	0.01755	0.01255	0.00833
12	0.16273	0.13403	0.13500	0.01755	0.01255	0.00833

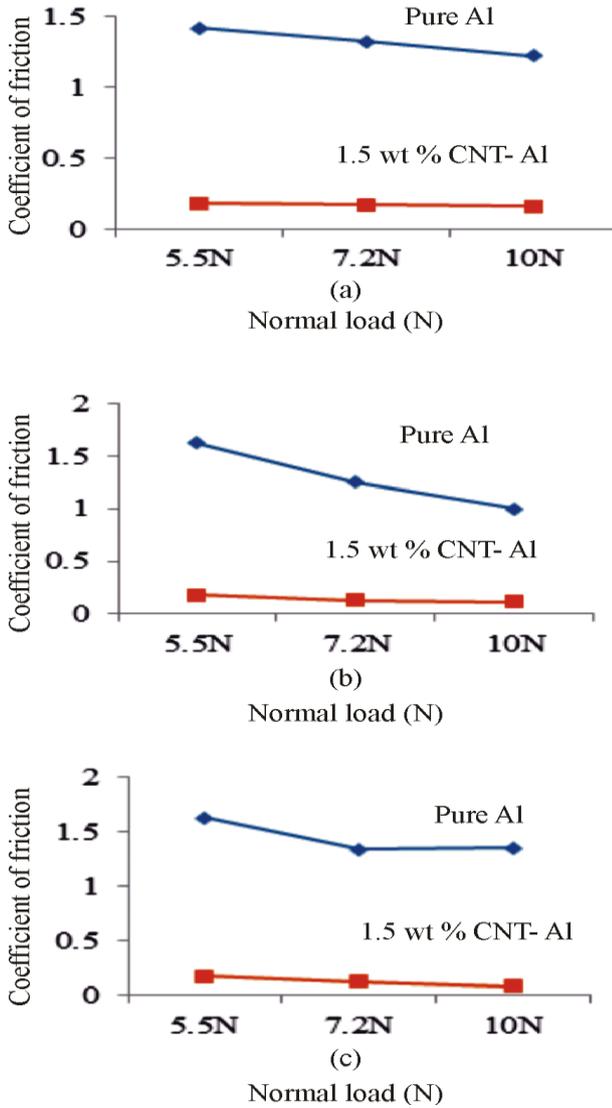
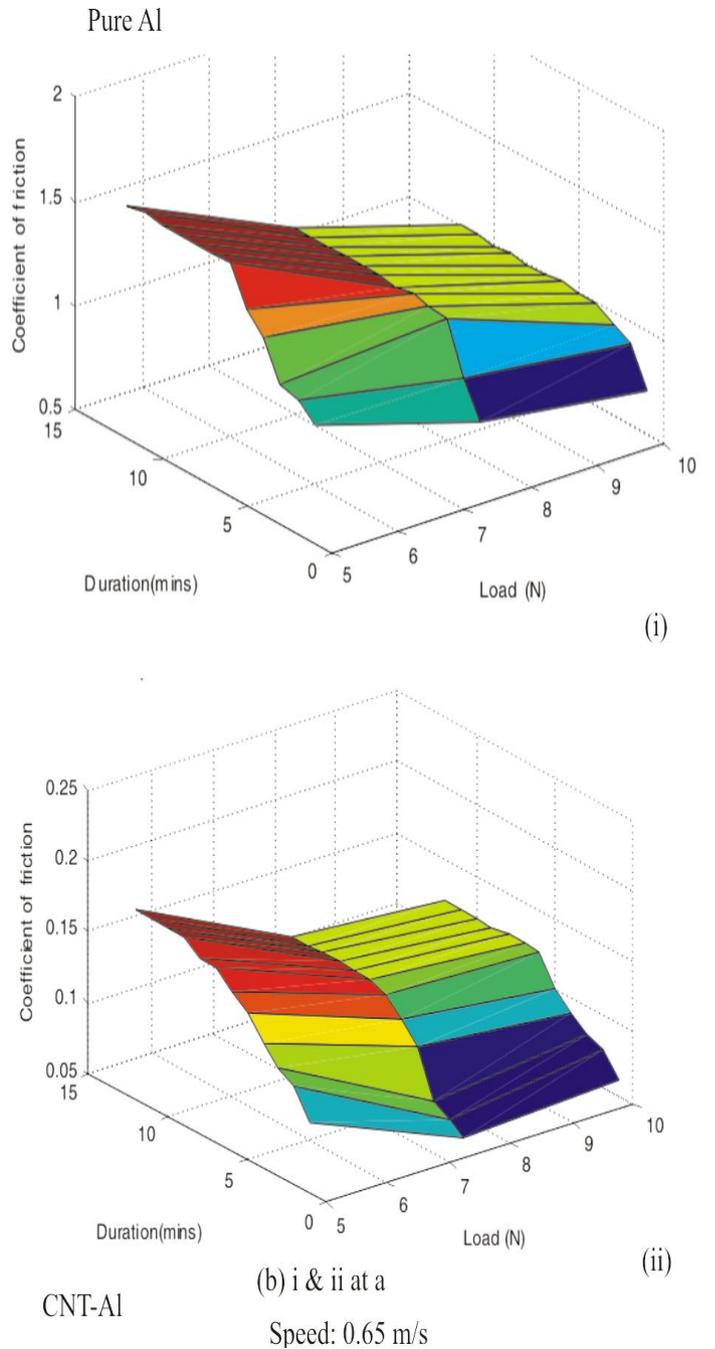


Figure 7: Variation of coefficient of friction at different normal load and sliding velocity (a) 0.5, (b) 0.65 and (c) 0.8 m/s for CNT-Al and pure Al

Coefficient of friction surface plot

Figure 8 presents the surface plot of Al and CNT-Al nanocomposite at 0.5, 0.65 and 0.8 m/s sliding speeds. The coefficient of friction are classified as low, medium and high due to the type of wear occurring at a time and corresponding wear was marked as mild adhesive, mixed adhesive and severe wear. From the experimental result, it was noticed that mild wear marks a smooth surface with minimum plastic deformation and oxide wear debris as a result of the frictional force acting on it. From the analysis of wear worn surface using surface roughness analyser it was found that severe wear results in a rough surface that was typically rougher than the original surface, with large plastic deformation and flake-like metallic wear debris. Severe wear leads to maximum coefficient of friction as a result of the high amount of frictional force. CNT-Al nanocomposite exhibited lower frictional coefficient than pure aluminium and it increases with decreasing normal applied load. From the surface plot it was observed that friction coefficient decreased with increasing CNT content from 0-1.5 wt % and

increase slightly from 1.5-2 wt %, then increase rapidly at 2.5 wt % CNT content. During dry sliding, an increase of any of the operating conditions such as normal applied load, sliding velocity, or duration of rubbing leads to an abrupt change in coefficient of friction (friction force per normal applied load). From the surface plots of coefficient of friction, it was deduced that CNT content, sliding speed and normal applied load has a significant effect on the wear and friction properties of the developed CNT-Al nanocomposite.



Note: Coefficient of friction (10-2) for all the,

- Mild adhesive wear $\mu \leq 0.12$
- Mixed adhesive wear $\mu \leq 0.18$
- Severe wear $\mu \geq 0.18$

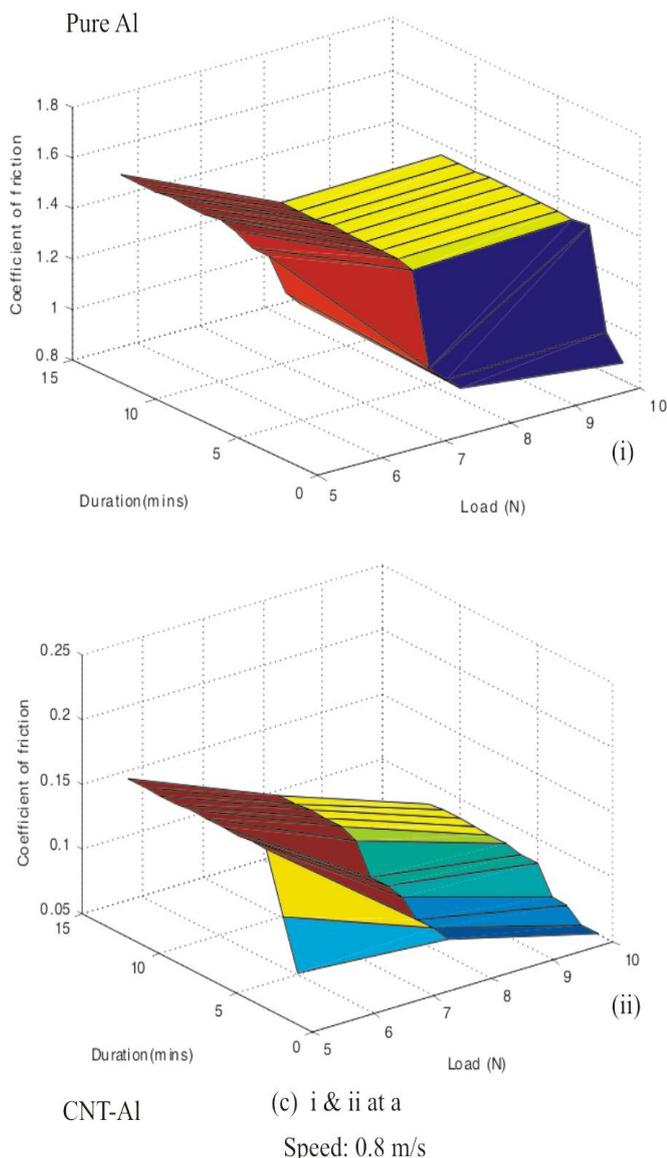


Figure 8: Surface plots for the coefficient of friction at: (a) 0.5, (b) 0.65 and (c) 0.8 m/s sliding velocity showing the wear region for the Al and CNT-Al nanocomposite material as i & ii respectively

CONCLUSIONS

Friction coefficient varies with the time of rubbing, significant change was experienced for Al before it became steady and a slight change was observed for CNT-Al for a certain time and it became steady. The value of frictional force was affected greatly by normal load and sliding velocity. The value of coefficient of friction decreases with the increase in normal load for both CNT and Al. On the other way, the values of coefficient of friction increase gradually with the increase in sliding velocity for Al, whilst in the case of CNT-Al the value of coefficient of friction increases slightly with the increase in sliding velocity.

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