TRIBOLOGICAL BEHAVIOUR OF NANO FERROFLUID IN AISI 1005 STEEL

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ABSTRACT

This paper details about the preparation and utilization of nano ferrofluid dispersed liquid lubricant in engine oil to analyse wear, coefficient of friction, frictional heat occurred between the mild steel pin (AISI 1005) and the disc of pin-on-disc wear tester. 0.5%, 1%, 1.5% and 2% by weight of magnetic particles (Fe_3O_4) prepared by wet chemical method were mixed into SAE 40pride engine oil liquid lubricant by sonochemical method. The resultant nanofluid reduces wear, frictional heat and coefficient of friction considerably when used as lubricants in the wear tester at different loads. Among the various nano fluids, 1.5% ferrofluid particles impregnated nanofluid exhibit very good results in comparison with other combination of nano fluids. The nanofluid prepared in this method representedas best lubricant, coolant, etc. which could be considered as an efficient liquid lubricant for many types of applications in near future.

Keywords: *Abrasive wear, Frictional heat, Ferrofluid, Pin-on-disc, Coolant*

1. INTRODUCTION

Whenever two contacting bodies slide, roll or moving with respect to each other, a force called friction is produced at their interface which opposes their movement. This friction force is usually accompanied by wear, the removal of material from either or both of the contacting surfaces [1-2]. Friction and wear further aggravated by contamination, corrosion, or unusual environmental conditions etc. However, both effects can be minimized to a greater extent by the process of lubrication[3]. Conventionally, the substances which are used for reducing friction is adsorbed layers of oxygen, oxide films (including rust), contaminants, dirt, oil, grease, various chemical-conversion coatings (sulfides, phosphates, etc.), and solid lubricants like graphite, MoS_2 etc. Moreover, many of these materials could not be chosen as lubricants since the material itself may sometimes produces the problems like abrasiveness and leads to friction and wear [4].

The modern machinery and equipment has required increasing performance of lubricating fluids and coolants which plays important role in the reduction of friction especially occurred with the metal parts [5-6]. The continuous search for fluids of high performance increases the attention of researchers, nanofluids have been found to possess enhanced thermo physical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients etc. [7-9]. In the past few decades, rapid advances in nanotechnology have led to emerging of new generation of coolants called "nanofluids". Nano fluids are a new class of nano technology based fluids engineered by dispersing nano particles in to conventional heat transfer fluids such as water, ethylene glycol and engine oil.Numerous experimental works have proved that the suspension of nano particles in fluids modifies almost all the properties of fluid [10-12].

Moreover, limited number of reports are available by employing the utilization of ferrofluid (FF, magnetite) dispersed nano fluid either as heat transfer media or coolants. Ferro fluids are stable colloidal suspensions of Fe_3O_4 (magnetite) nano particles dispersed in aqueous medium [13]. Suspending magnetite in any liquid imparts unusual properties to the liquid. Magnetic anisotropic nature has been developed while on suspending nano ferrofluid in the presenceof magnetic field [14]. Compared to conventional liquid lubricants, nano fluids possess great advantages like high dispersion stability, reduced particle clogging, high thermal conductivity, surface wettability etc., all depends on particle concentrations [15]. Also, Nano FF in different suspending media has variety of applications, including zero-leakage rotary shaft seals [16], heat transfer in audio loud speakers [17], biological applications like targeted drug delivery [18], tracer's flow [19], as MRI contrast agents [20], in electronic packing and in other applications.

This report envisages about the dispersion of moisture free magnetic nano FF in to liquid lubricant like engine oil, obtained a new class of nano fluid. Placing this novel nano fluid in between the oppositely moving objects like pin and the disc in the pin-on-disc wear tester dramatically modifies many mechanical properties naturally found in the machines like wear, coefficient of friction, frictional temperature etc.

2. EXPERIMENTAL PROCEDURE

2.1 Specimen preparation

The mild steel (AISI 1005) of 0.05% C steel rod was machined into a pin of 8 *mm* diameter and 30 *mm* height. Before carrying out the wear test, mild steel pins were mechanically polished to 1000 grit finish, and ultrasonically degreased with acetone. Then sequence of cleaning was performed to remove contamination on the substrate surface. The steel substrates were activated for 20 *s* in a mixed acidic bath to remove scaling on the surface.

2.2 Synthesis of ferrofluid

0.1117 *g* of pure iron powder was mixed with 5 *ml* of concentrated hydrochloric acid and kept over the hot plate. After the evaporation of acid, a pale greenferrous chloride [$Fe(II)Cl_2$] powder was obtained. After cooling the ferrous chloride solid, it was dissolved in 2 *ml* of distilled water. 1.08 *g* of anhydrous Ferric chloride [$Fe(III)Cl_3$]was dissolved in 4 *ml* of distilled water in another beaker. Ferrous chloride solution was stirred vigorously in a magnetic stirrer;ferric chloride solution was added in drop wise manner to ferrous chloride solution. 50 *ml* of ammonia solution was added slowly into the mixture consisting of Fe (II) and Fe (III) solutions using a dropper for a period of 0.3 *ks* and stirred continuously for about 1.2 *ks*. After an initial brown precipitate formation, a black precipitate was obtained finally (magnetite). The magnetite particles were allowed to settle, the supernatant liquid was discarded without losing any dark black viscous ferrofluid particles. Further,unreacted components were removed from the mixture by stirring with 150 *ml* of distilled water. Sedimentation of the ferrofluid has been accelerated by keeping a circular magnet below the beaker, the clear liquid obtained after 0.6*ks* were discarded. This operation was repeated for 4 to 5 times. Finally, the trace amount of water molecules being present along with ferrofluid was removed by inverting the beaker along with magnet for 1.8 *ks*. Dark black coloured viscous semisolid obtained was used as such for the preparation of nano fluid.

2.3 Nano ferrofluid dispersed engine oil

1000 *ml* (863.87 *g*) of SAE 40 (servo pride, India) lubricating oil was taken in 1000 *ml* beaker. 4.3194 *g* [0.5%; wt. /wt. basis] of water free ferrofluid particles were dispersed and sonicated (Sonics Model: VCX 750, Frequency-20 *kHz*) for about 1.8 *ks*. Lubricating oil containing ferrofluid nano particles appeared like turbid suspension, henceforth settling of nano particles never happened. By adapting similar procedure, 1.0%, 1.5%, and 2.0% of ferrofluid was prepared by mixing 8.6382, 17.2764, 34.5528 *g* of ferrofluid respectively in to 863.87 *g* of lubricating oil individually. As obtained nano ferrofluid (FF) loaded engine oil are named as pure engine oil – PEO, 0.5% FF + engine oil – 0.5 FFEO, 1.0% FF + engine oil – 1.0 FFEO, 1.5% FF + engine oil – 1.5 FFEO and 2.0% FF + engine oil – 2.0 FFEO.

2.4 Characterization

Particle size of the obtained ferrofluid nano particles were measured using zetasizer-size distributor (Zetasizer, Malvern Instruments Ltd, UK) in aqueous medium. The synthesized nano ferrofluid particle size was measured using zeta seizer is shown in Fig.1. The intensity data of the ferrofluid particles were measured in aqueous medium. The size of the particle is found to be 13.54 *nm* with mono dispersive nature.

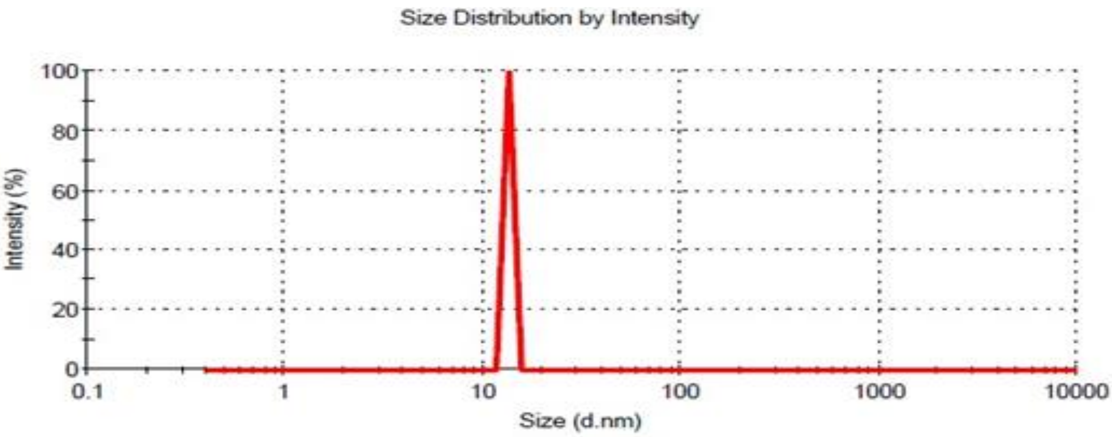


Figure 1 Particle size analysis for ferrofluid.

2.5 Wear test

A "pin on disc" (Ducom, TR-20LE-PHM-400, India) wear testing machine was used for the determination of wear, pin temperature, etc., of AISI 1005 steel. The samples taken for wear tests were pins of 8 *mm* diameter and 30 *mm*heightwhich fit into the pin holder of wear testing machine. The rotating disc was made of hard stainless steel of 160 *mm* diameter (ASTM G99) fit into the fixture.Prior to testing, the weights of the pin were measured. Thepin was fixed vertically above the horizontal rotating disc and gently touches the disc. The sliding distance of the pin was fixed as a variable parameter for wearing. Initially, the wear tester was filled with 1 *l* of engine oil without any additives into the chamber exist in pin-on-disc wear tester. Various aspects of mechanical properties like wear, pin temperature and COF, etc. were recorded at different loads (5, 10 and 15 *N*). After noting down all the values, the oil chamber was emptied, thoroughly cleaned with plain engine oil to remove worn particles. Adopting similar procedure, the wear and other properties exits in between pin and disc were examined by using 0.5FFEO, 1.0FFEO, 1.5FFEO and 2.0FFEO individually. From the change in weight of pin, the percentage in weight loss has been calculated using the Eqn.1. After completion of the experiment, the pin was carefully remove and cleaned by rinsing with acetone and weighed. Wear and other characteristics studied earlier were also tested by raising the temperature of the pin to 100°*C*. From the values of friction force and load applied, the coefficient of friction was calculated from the Eqn.2. The rotating disc was rotated at 500 *rpm* for all the wear tests performed in this investigation. Various experimental parameters maintained during the processesare given in the Table 1.

$$\%\ of\ Weight\ loss = \frac{Weight \cdot of \cdot the \cdot samples \cdot before \cdot wear \cdot test}{Weight \cdot of \cdot the \cdot sample \cdot after \cdot wear \cdot test} X100 \quad (1)$$

$$Coefficient\ of\ friction = \frac{Friction \cdot force}{Load} \quad (2)$$

Track diameter *(mm)*	Speed *(rpm)*	Time *(sec)*	Temperature *(°C)*	Sliding distance *(m)*
80	500	960	35 & 100	2000

Table - 1 Experimental parameters of wear test

3. Results and discussion

3.1 Analyses of Mechanical properties

Under the operating conditions of pin-on-disc wear tester, ferrofluid dispersed lubricating oil has been used to study the evaluation of wear, coefficient of friction and pin temperature in comparison with the fluid which is free from nano particles. While performing the wear test analysis, it is noted that the behaviour of wear, temperature of the pin and the coefficient of friction being considered are greatly influenced.

3.2 Wear resistance

Wear is an important factor associated with engineering components especially those objects which are in moving condition. Generally wear of the metallic objects are being minimized by the utilization of wear resistant alloys and placing some quantities of lubricating medium like grease or lubricating oil. Effect of nano

FF blended engine oil towards the reduction of wear is described by following the experimental details given in sec. 2.5.

The extent of wear associated in between the pin and the disc were recorded at two different temperatures (35°*C*& 100°*C*) by the interposition of PEO and other blended oils. Fig.2 (a-b) represents the characteristics of wear corresponding to the usage of pure and other blended oils.

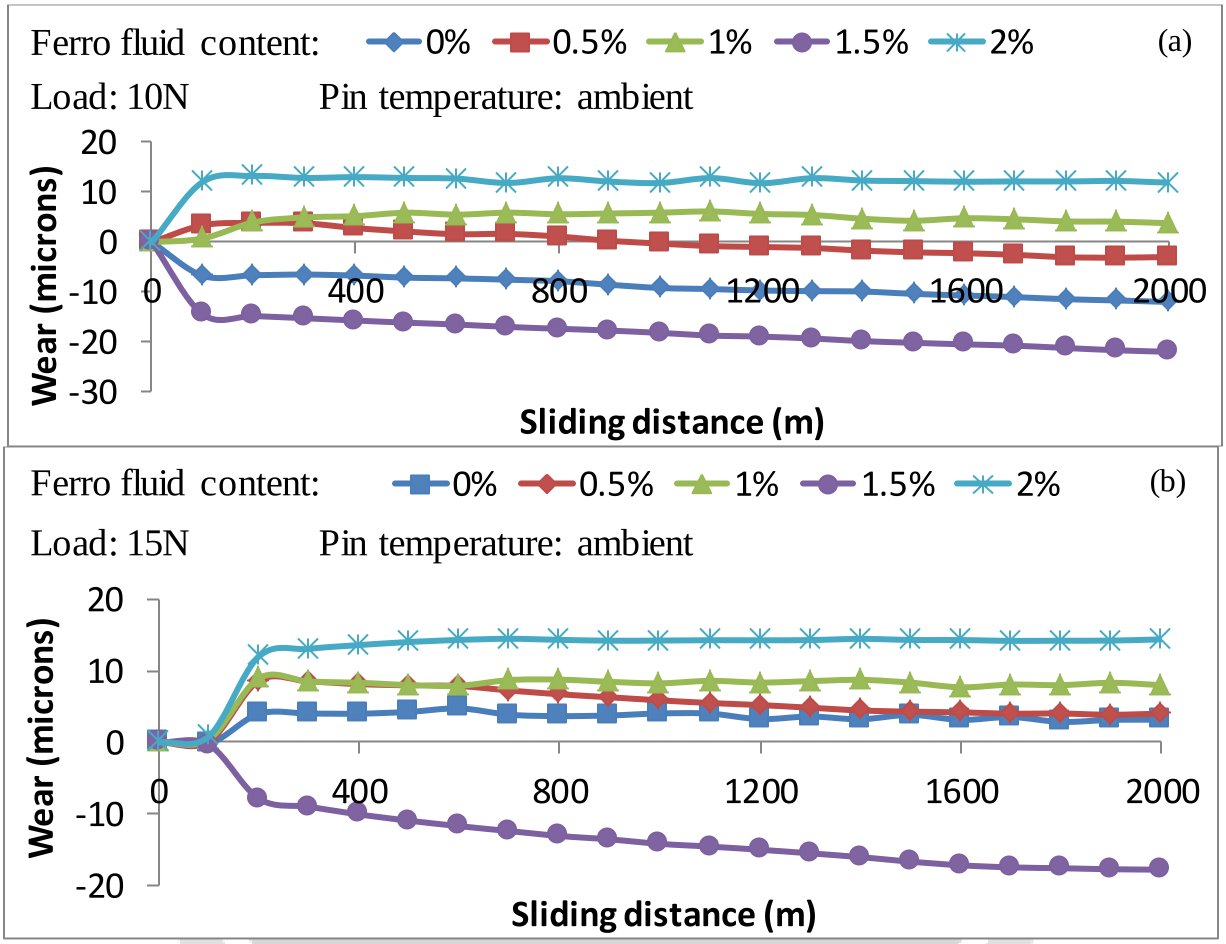


Figure 2 (a-b) Wear behaviour of mild steel under ambient conditionfor different loads.

From the Fig.2 (a-b) it is clear that, considerable amount of wear taking place on using PEO i.e., around -12at the load of 10N whereas 0.5FFEO and 2.0FFEOexhibits the wear about -3 and 12.2 *μm*respectively. Interestingly, 1.0FFEO and 1.5FFEOreduce the wear to negative values like 4 and -21.96*μm* respectively. All these results are taken under the operating load of 10*N*. A similar trend is also observed by increasing the load from 10*N* to 15*N*. Except for 1.5FFEO all other compositionsdisplays positive wear and the values are summarised in Table2.

Engine oil	Wear (*microns*)			
	Load, Ambient temperature		Load, Pin temperature 100°*C*	
	10*N*	15*N*	5*N*	15*N*
PEO	-11.97	3.17	1.54	6.06
0.5FFEO	-3.00	4.04	-10.65	3.46
1.0FFEO	4.11	8.23	12.34	15.94
1.5FFEO	-21.96	-17.8	-11.70	-8.95
2.0FFEO	12.27	14.40	16.63	18.78

Table 2 Wear behaviour of mild steel under ambient and 100°*C*for different loads.

Change in wear is also recorded by maintaining the pin temperature at $100^{o}C$ by keeping all other parameters as constant. Fig.3(a-b) shown below is the characteristic curves recorded for a sliding distance of 2000*m* with a load of 10*N*and 15*N*. At high temperature, the plain lubricating oil itself exhibit higher wear 1.54 and 6.06 *μm*for the load of 10*N* and 15*N* respectively. However, the change in wear is getting minimized while using the ferrofluid loaded engine oils. Wear associated with different percentages of ferrofluid loaded lubricating oil is given in the Table 2.

At high pin temperature, in comparison with the characteristics of wear obtained for plain lubricating oil, 1.5FFEOshows lesser wear for both loads. Wear noted down at 100°*C* is comparably higher than those appeared in the case of ambient temperature. Obviously, this may be due to the higher operating pin temperature. Since at high temperature, degradation of metallic surface takes place at faster rate.

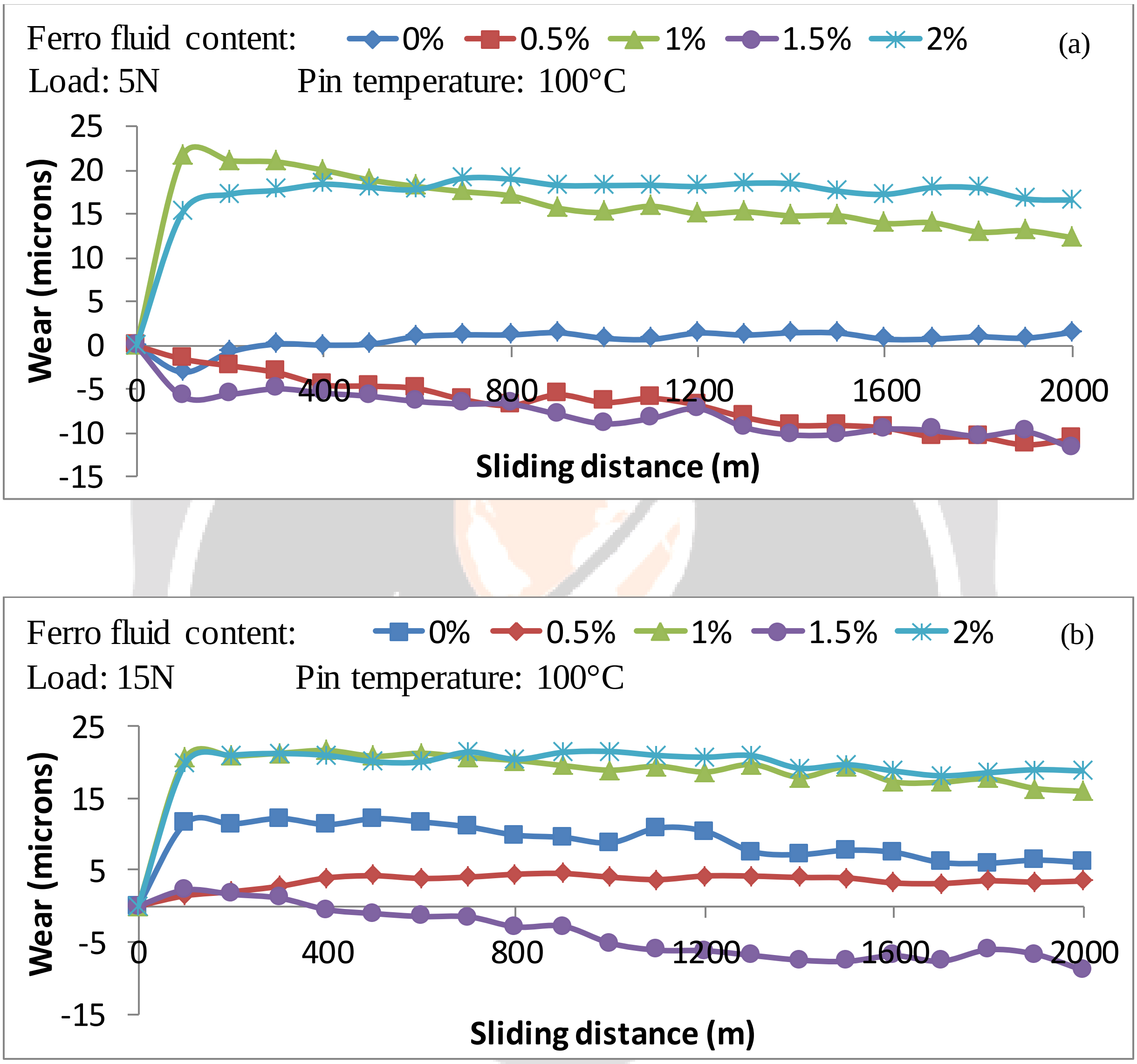


Figure 3(a-b) Wear behaviour of mild steel under 100°*C*for different loads.

3.2.1 Effect of nano fluid against pin temperature

Fig.4 (a-b) displays the change in temperature of the pin obtained during the running of a wear tester under the load of 5*N* and 10*N*load respectively. In this case, the initial temperature of the pin is maintained at room temperature.

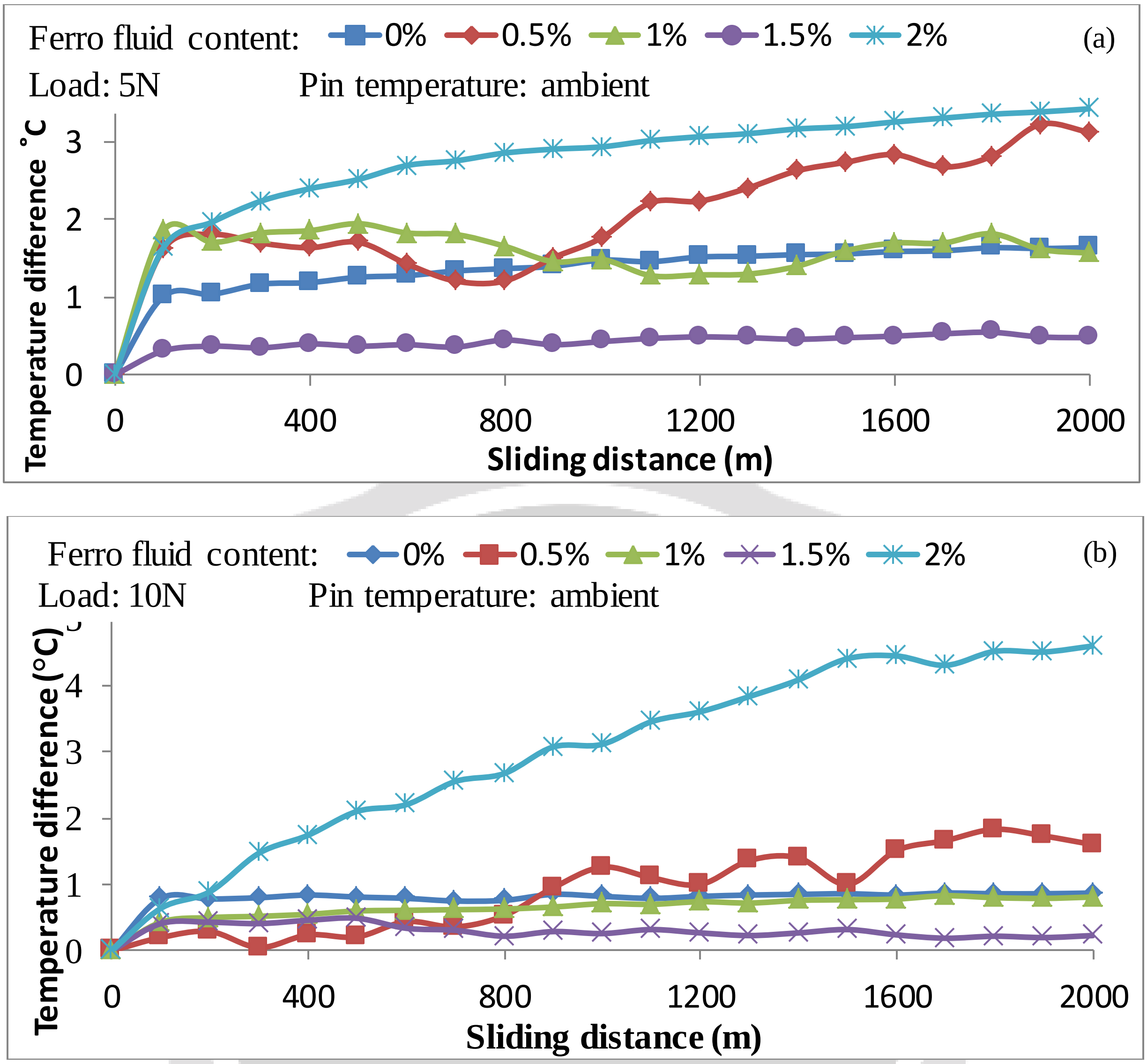


Figure 4 Pin temperature difference at ambient condition for (a) 5*N* (b) 10*N*.

On varying the composition of the nano ferrofluid particles, the temperature attained by the pin is also changed. The temperatureof the pin increases above room temperature (30^{o}C) in the order of about 2°*C*. The results obtained are detailed in Table 3.

Engine oil	Pin temperature difference (°*C*)	
	5*N*	10*N*
PEO	1.64	0.87
0.5FFEO	3.23	1.83
1.0FFEO	1.82	0.83
1.5FFEO	0.55	0.23
2.0FFEO	3.43	4.59

Table 3 Change in pin temperatureof wear tester operated atdifferent load condition

From the data, it is noticed that, the temperature of the pin rose to 1.64°*C*(5*N*) and 0.87°*C*(10*N*) on running with PEO. But at the same time, the temperature of the pin is increased to 3.23°*C* and 1.83°*C* on using 0.5FFEO. However, higher percentage of ferrofluid dispersed nano fluid reduces the pin temperature considerably in the same conditions being adopted. Compared to 0.5FFEO, 1.0FFEO enhances the temperature to 1.82°*C* and 0.83°*C*respectively. Obviously this value is much lower than those fluids containing 0.5FFEO. A noteworthy feature observed for the nano fluid containing 1.5FFEO which exhibits least increase in pin temperature (0.23^{o}C& 0.55^{o}C for 5*N* & 10*N* loads). The pin temperature was significantly increased for

2.0FFEO toas 3.43°*C* and 4.59°*C* under the load of 5*N* and 10*N* respectively. This may be due to the accumulation of nanoparticles on the pathway of the pin. The same trend is also noticed in the coefficient of friction and wear studies also.

3.2.2 Measurement of COF

Frictional forces operating in between the moving objects have been reduced by placing considerble quantity of lubricants. The coefficient of friction is the ratio between the frictional force and load is also dependent on the type of lubricants used. By employing suitable lubricating materials, the COF can be controlled well.

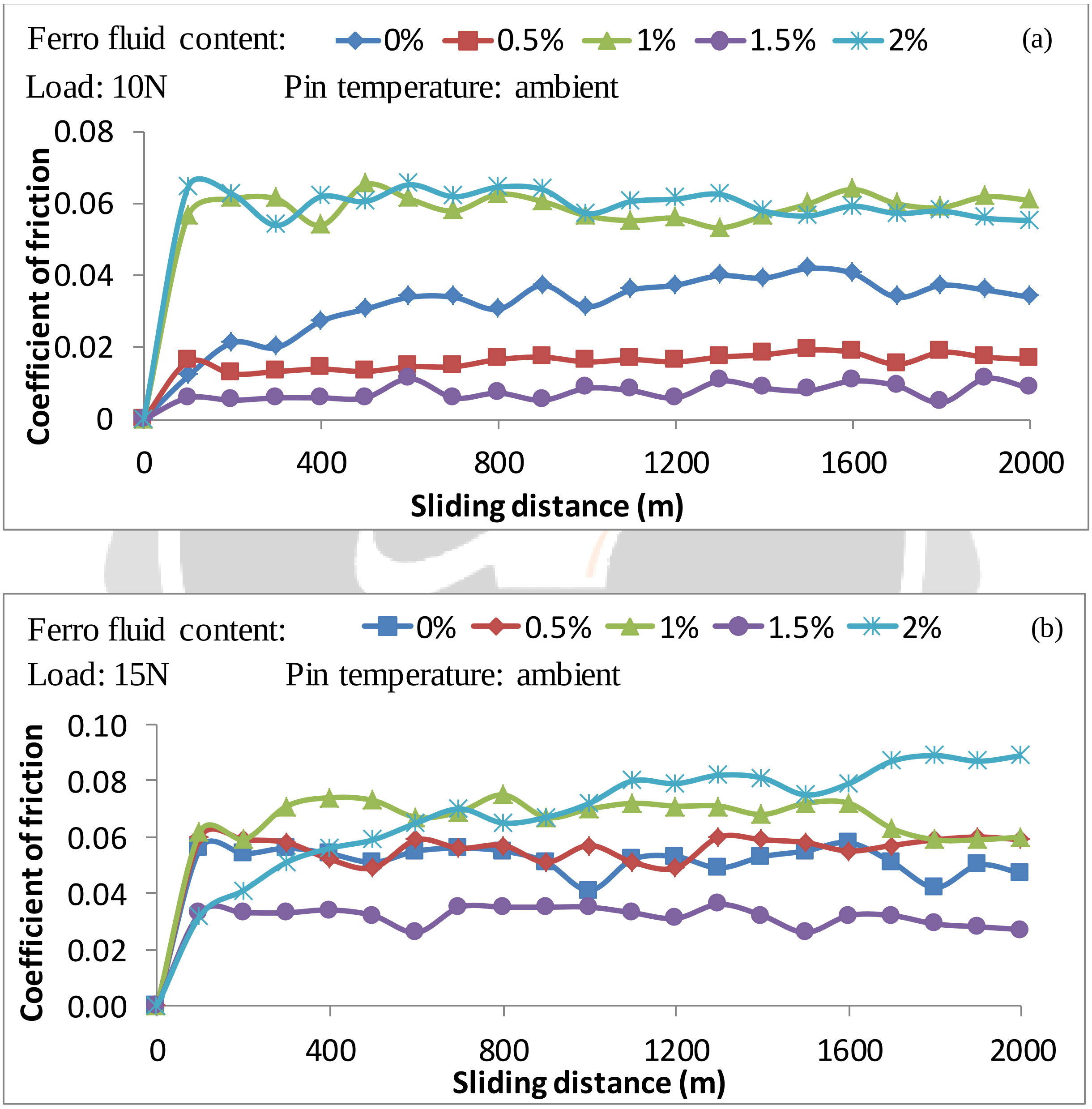


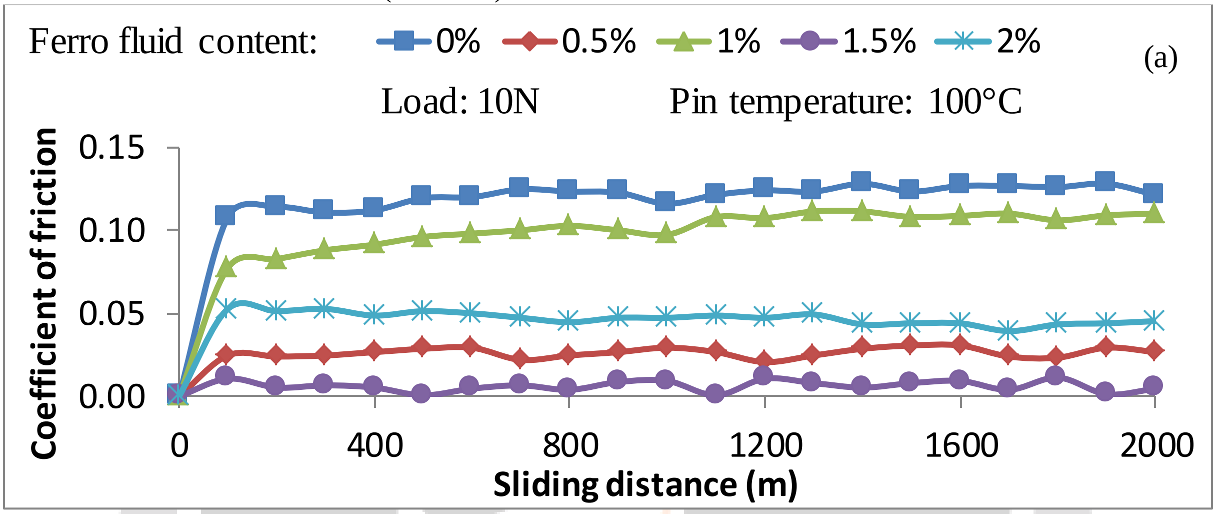
Figure 5(a-b) COF for mild steel under ambientfor different loads.

Fig.5 (a-b) shows the coefficient of friction value for mild steel pin-on-disc recorded under ambient conditions with different loads of 10*N* and 15 *N*. The COF values of PEO at 10*N* and 15*N* load is 0.0345 and 0.0470 respectively. These values are reduced to 0.0086 (10*N*) and 0.0275 (15*N*) by using the 1.5FFEO. 0.5FFEO exhibit the COF value as 0.0166 & 0.0591 operated under the load of 10*N* and 15*N*. The COF value obtained for blended engine oil is given in Table 4.

Engine oil	Coefficient of friction				
	Load, Ambient temperature		Load, Pin temperature 100°*C*		
	10*N*	15*N*	5*N*	10*N*	15*N*
PEO	0.0345	0.0470	0.1380	0.1213	0.0548
0.5FFEO	0.0166	0.0591	0.0836	0.0266	0.4726
1.0FFEO	0.0612	0.0698	0.0549	0.1156	0.0680
1.5FFEO	0.0086	0.0275	-0.0071	0.0046	0.0274
2.0FFEO	0.0553	0.0893	0.1762	0.0453	0.1523

Table 4COF values of pin-on-disc recorded under ambient and at 100°*C*for different loads.

Keeping all other parameters as constant, the COF values also recorded by mainitaining the pin temperature at 100^o*C*. Fig.6(a&b) represents the characteristics of COF studied at 100^o*C* employing the engine oils with and without the additives (Ferrofluid).



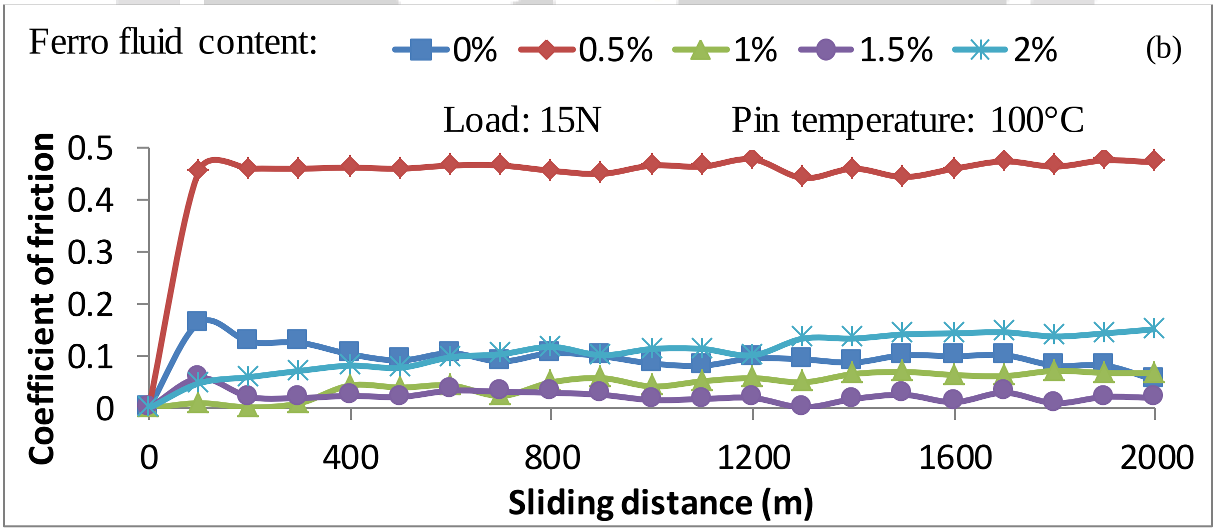


Figure 6(a-b)COF for mild steel under 100°*C*for different loads.

From the Fig.6 (a-b) it is evident that, the COF values of the oil without additives measured at higher temperature is higher than those measured at room temperature. The engine oil mixed with varying percentages of nano ferrofluid reduces the COF values considerably. All COF values associated with these processes are tabulated in Table IV. From the data, it is noticed that the 1.5 FFEO shows a very low COF values 0.0046 (10*N*) and 0.0274 (15*N*) than other combinations of lubricating medium.

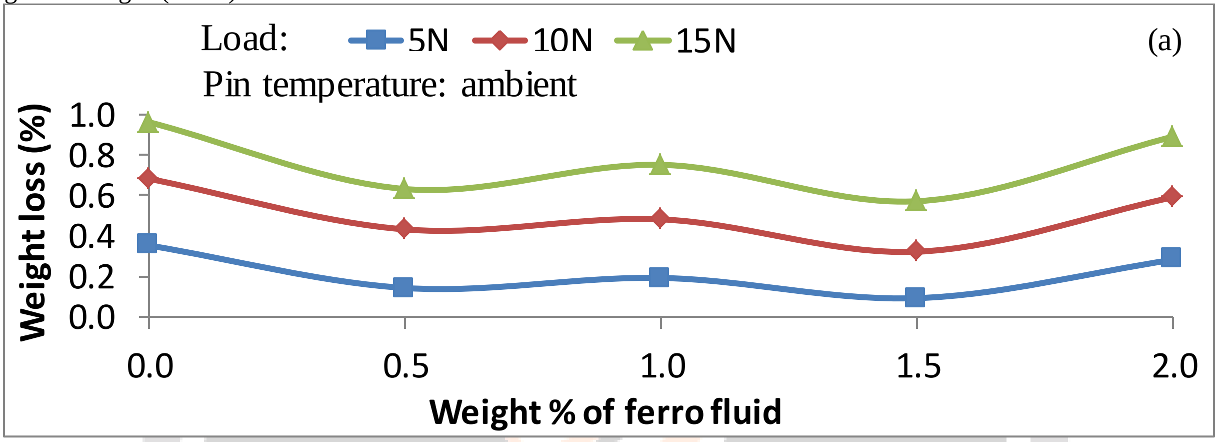
3.2.3 Measurement of weight loss

Nano FF blended engine oil effectively reduces wear, pin temperature and COF of pin-on-disc. Obviously, the percentage weight loss associated with the pin in these environment will become less. The change in weight noticed on the pin (weighed before and after the experiments) for the series of experiments are summerized in Table 5.

Engine oil	Weight loss (%)					
	Load, Ambient temperature			Load, Pin temperature 100°*C*		
	5*N*	10*N*	15*N*	5*N*	10*N*	15*N*
PEO	0.35	0.68	0.96	1.35	4.85	15.47
0.5FFEO	0.14	0.43	0.63	3.98	6.95	20.87
1.0FFEO	0.19	0.48	0.75	1.63	5.36	17.08
1.5FFEO	0.09	0.32	0.57	0.89	2.96	9.65
2.0FFEO	0.28	0.59	0.89	4.87	9.86	25.68

Table 5% of weight loss occurred on mild steel pin recorded at 35°*C* at 100°*C* under different loads

The percentage of weight loss associated with pin is plotted against different lubricating media are given in Fig.7 (a & b).



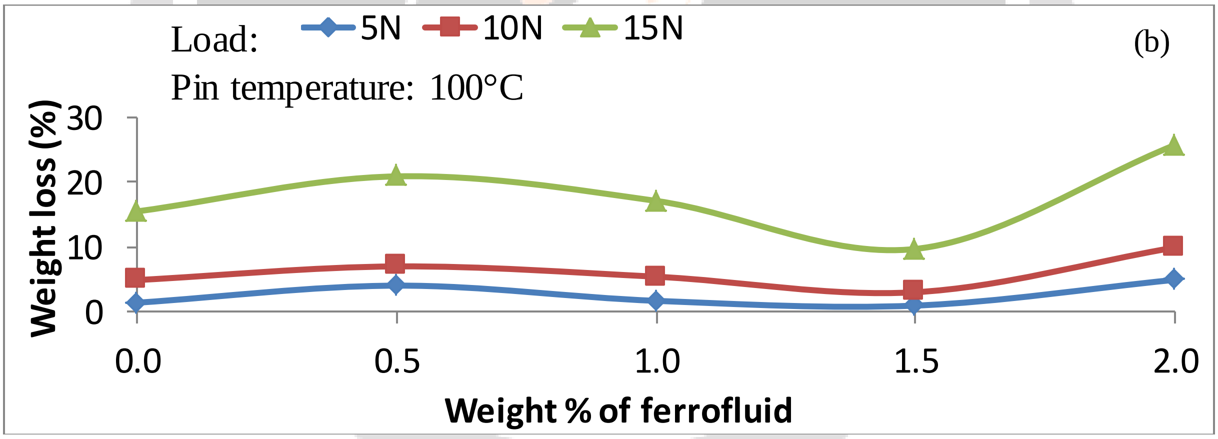


Figure 7(a & b) Weight loss for mild steel pin under ambient and 100°*C* for different load.

Fig.7 (a) illustrates the weight loss of pin tested under ambient whereas Fig.7(b) is recorded by maintaining the pin temperature at 100°*C*. From both the graphs, the change in weight loss associated with the pin is less for the medium containing 1.5FFEO. PEO and 2.0FFEO mediums exhibit higher weight loss in comparison with other oils. Because,PEO viscosityisreduce to while conducting the wear test.

4. Conclusions

The conclusion that can be derived from the above analysis is as below:

- Different proportions of ferrofluid in weight basis were mixed with the engine oil and the resultant fluid obtained was used as coolant, efficient lubricating medium in pin on disc wear tester.
- Among the different combinations of ferrofluid mixed with oil, 1.5FFEO mixed medium reduces the frictional temperature developed on the pin to a greater extent when compared with other proportions during the analysis.
- 1.5FFEO reduces not only the pin temperature but also reduces the wear, COF etc. to greater extent.
- The percentage of weight loss of the pin after conducting the experiment is also found to be less at using 1.5FFEO.

- The nanofluid prepared in this method represented as best lubricant, coolant, etc. which could be considered as an efficient liquid lubricant for many types of applications in near future.

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