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The Effect of Micro and Nano-Lubrication on Tribological Properties of Sliding Pairs

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Abstract

A pin-on-disc type wear testing machine is used to study the tribological performance of brass- steel pair. The test pins were made of brass (cu-zn) with a diameter of 8 mm and a length of 20 mm. The preliminary tests were conducted using counter surface disc of steel with a diameter of 120 mm. All these tests were performed in dry condition. Then experiments were carried out using two types of lubricants i.e micro and nano graphite with paraffin oil. Lubricating conditions were facilitated by suitably modifying the existing high temperature pin-on-disc tribometer. Wear depth (in microns) was measured by LVDT (Linear variable differential transducer) in the tribometer during the tests then it is converted into wear rate. For high temperature experiments, the brass pin was inserted into cartridge heater assembly with thermo couple (K type) based temperature controller. Experiments were carried out with temperature at 50^{0}C and 100^{0}C . Wear depth (micron) is directly proportional to load in both dry condition and dry condition with heating temperature 50^{0}C. The coefficient of friction and wear depth both are exhibiting similar trend with increase in sliding velocity at dry sliding condition and lubricated condition. In dry condition at temperatures (50^{0}C) the coefficient of friction increases with increasing load, where as in lubricated condition at temperatures (50^{0}C) the coefficient of friction decreases with increasing load. Variation of wear depth is marginally increasing with load in lubricated condition at temperature 50^{0}C.

Keywords: *Tribology, Brass steel pair, Nano lubrication, Wear depth, Co- efficient of friction.*

1. INTRODUCTION

The recent world is driven by modern technologies with higher efficiency. Scientists are now involved in reducing different losses so as to improve efficiency in mechanical systems. Friction is the main culprit of losses in mechanical systems developed at contact areas. Tribology is the science of friction, wear, and lubrication between interacting surfaces by relative motion. The study of tribology is commonly applied in bearing design but extends into almost all other aspects of modern technology. Any product where one material slides or rubs over another is affected by complex tribological interactions, whether lubricated like hip implants and other artificial prosthesis or unlubricated as in high temperature sliding wear in which conventional lubricants cannot be used but in which the formation of compacted oxide layer glazes have been observed to protect against wear.

Tribology plays an important role in manufacturing. In metal-forming operations, friction increases tool wear and the power required to perform the operation. This results in increased cost due to more frequent tool replacement, loss of tolerance as tool dimensions shift, and greater forces are required to shape the workpiece. A layer of lubricant which eliminates surface contact virtually eliminates tool wear and decreases the needed power by one third. The application of correct tribological practices can protect and enhance the life of plants and machinery, improve efficiency of operations, reduce energy consumption and prevent expensive breakdowns. Major organizations and academic institutions in the country have realized the importance of industrial tribology and its relevance to modern design and efficient plant maintenance. The movement of one solid surface over another is important to the functioning of mechanisms.

The satisfactory operation of joints for example doors or human hip joints bearings and bushes. The behaviour and effect of forces within materials is a basic subject recognized in engineering design. The view that tribology, in general, and tribo design, in particular are intrinsic parts of machine design can be further reinforced by a brief review of tribological problems encountered in the most common machine elements.

Brass is used in friction parts of machines, such as bearing liners, bushing, etc. Furthermore, it is known that the wear of metal involves complicated phenomena such as metal transfer, mechanical alloy-forming process; abrasive and adhesive wear, and wear transitions. Analyses of the surface layer developed during dry sliding against steel have shown good correlations among composition, hardness and wear resistance. It is assumed that wear processes are mainly determined by mechanisms of surface film formation and destruction. The major phenomenon in the brass–steel couple is the transfer of the brass particles to the steel disc due to the abrasion of the softer metal on the harder material. This process takes place without interruption and reacts with atmospheric oxygen which leads to brass film formation. The sliding track is almost totally covered with brass film and this layer protects the surface from the hard asperities of the steel disc continued sliding results in an increase in the transferred brass and deposited metal until the detachment of the brass particles occurs. Similar metals sliding on each other there is a significant contribution to friction owing to severe ploughing. For dissimilar metals the friction coefficient is determined primarily by the way metal transfer occurs between sliding surfaces. While the pin-on-disc friction coefficient-sliding distance results agree in general with those of the crossed cylinder tests (in which a static cylinder is loaded against a rotating cylinder). There are some distinct differences in the absolute magnitudes of the friction coefficients owing to variations in the ploughing intensity, metal transfer and embedding as affected by the two test geometries.

Bai and Biswas (1984)[1]have studied the dry sliding wear behaviour of aluminium alloys containing 4-24 wt. % Si in the speed range 0.19-0.94 m/s and concluded that the wear rate was insensitive to variation in sliding speed over the pressure range of 0.1-1.7 MPa. A more or less similar conclusion was arrived by Andrew et al.[2] after testing Al-{17-26) wt.% Si alloys in the speed range 1.6 – 4 ms^{-1} Further, they reported that the transition load decreases as the slidings peed is increased. By transition load, these workers meant that load at which aluminium alloy started to form thick transfer patches, making further running of the test difficult. Okabayashi and Kawamoto (1968)[3] observed that aluminium alloys containing up to 15 wt.% Si exhibit a transition from mild wear to severe wear. However, the wear rate for a 21.6 wt.% Si alloy remained constant at a lower level without any transition when slid against itself. Further, when the Al-21.6wt.%Si alloys was slid against steel, the wear rate decreased with increasing sliding speed, reached a minimum at 2.5 m/s and then increased.

Apart from the cast Al-Sialloys, some of the wrought aluminium alloys have been investigated under dry sliding conditions. For example, Okabayashi and Kawamoto[4] investigated the wear of wrought alloys such as Al-Cu and Al-Zn-Mg alloys and have reported that, in the case of steel counterfaces, the wear rates of the si-al alloys decreased upto 1 ms^{-1} and then increased to higher values with a further rise in sliding speed. The transitions peed for cast iron counter faces was 4 ms^{-1}. The trend of decreasing wear rate with speed for Al-22 wt.% Si has been observed by Jasim [5]. He also showed that the depth of deformation in the subsurface region of the Al-22 wt.% Si alloy pin decreases with increasing speed in the range 0.85-5 ms^{-1}. Yamada and Tanaka [6] have recently observed that the wear rate for aluminium alloys with low silicon content increased with increasing speed, but aluminium alloys with a high silicon content lead to little variation in the wear rate. Bouchoucha(1995)[7] observed the metal transfer and oxidation in a copper-steel couple sliding electric contact are studied. During wear test the adhesive transfer and the oxide growth at the interface affect the tribology properties. The diffusion processes of oxygen in the transferred oxide layer is influences the oxide growth. In consequence the transfer and oxidation processes play an important role in the tribological behaviour of the copper-steel couple. The friction coefficient remained almost the same when rubbing occurs under air or oxygen, but it increases under argon. However, the wear increases under oxygen and diminishes in argon with respect in air. The mutual transfer of materials between the surfaces of brass and stainless steel shows that the zinc content is higher than the copper content not only on the worn surface but also on the worn disc surface. This is due to the surface atom diffusion. The diffusion process in friction is as follows as the friction surface layer bears the thermal and mechanical actions, both the temperature field and the stress field form, and a large temperature gradient and a large stress gradient occur. They cause an increase in the surface atom energy and a decrease in the barrier preventing surface atom diffusion. Because the friction surface is composed of asperities which are distributed randomly.

During sliding, it is remarked that the immediate effect, after only few revolutions of the disc, the copper transfer to the disc. Owing to the ductility of copper, the valleys between asperities are filled with copper that is transferred to the disc surface. In general this film is fairly thin and uniform over the entire surface. In the absence of oxidation, copper is essentially rubbing on copper. It appears that this layer protects the surface from the hard peaks of asperities of steel. Continued sliding results in an increase of the transferred copper, this is followed by loose wear debris formed on the transferred film. Growing by successive deposition of metal, the detachment of a particle of copper occurs.

Literatures available on the effect of nanolubricants on brass-steel sliding are scarce. Whenever there is a contact between solid bodies, surface phenomena, designated by friction of wear, are developed. The resistance to the relative motion between bodies rolling or sliding, in open or closed loop, with dissipation of energy is termed as friction .The frictional force is a tangential force that is common in the frontier of the bodies in contact. Wear is the progressive loss of material from the active surface of a body, by direct action of relative motion in that surface. Wear leads to a loss of efficiency of the mechanical components where they occur, with relevant economical implications. Therefore, the precise knowledge of the mechanical parameters, the sliding velocity, load and the temperature of the contact, the wear and the coefficient of friction, are extremely important. The temperature factor and also the velocity/load and load/temperature interactions have a great influence on the coefficient of friction. The wear is highly influenced by the load factor and, in a smaller degree, by the temperature. Nanotechnology has performed to be an important prospective technology since the advent of micro electromechanical systems including sensors and actuators. However, less workers has examined the effect of sliding speed on the wear behaviour over the entire range of speeds reported. Individual studies have concentrated on small speed ranges and consequently have drawn some contradictory conclusions. For these basic requirements the current study of sliding wear of brass steel couple using pin on disc wear testing has been performed under solid lubricant(micron size graphite particles),and nanolubricant (nanographite). This study hopefully is a better accumulation of information which will enhance newer researches.

2. EXPERIMENTAL

A pin-on-disc type wear testing machine as shown in Figure 4.1 is used to study the tribological performance of brass- steel pair. The test pins were made of brass (cu-zn) with a diameter of 8 mm and a length of 20 mm. The preliminary tests were conducted using counter surface disc of steel with a diameter of 120 mm. The fixed sliding distance was 1500 m. All the tests were performed in dry condition. Experiments are done with different loads such as 10N, 20N, 30N, 40N, & 50N at three different sliding velocities 1.5m/s, 2.5m/s and 3.5m/s.

Then experiments are carried out with using two types of lubricants i.e micro and nano graphite with paraffin oil. Micro-graphite (50µm) and paraffin oil with 20: 1 ratio is used as a lubricant. The graphite has density of 2.25gm/cm^3 and oil has density 0.87kg/m^3 and grade of SD65550749. The kinematic viscosity is 64 cs. The solution is made by mixing of 3 ml oil with 0.1gm micro graphite. The same experimental conditions are maintained as that of dry condition. The mixture of paraffin oil and nanographite (35nm) is prepared by the 0.1 gram nanographite added to the paraffin oil and sonicated for 30 minutes to ensure uniform dispersion of the graphite nanoparticles. Lubricating conditions were facilitated by suitably modifying the existing high temperature pin-on-disc tribometer. Wear depth (in microns) was measured by LVDT (Linear variable differential transducer) in the tribometer during the tests then it is converted into wear rate. For high temperature experiments, the brass pin was inserted into cartridge heater assembly with thermo couple (K type) based temperature controller. Specified temperature of the brass pin is increased from cartridge heater by the heat conduction. Good surface contact between the brass pin and cartridge heater and also

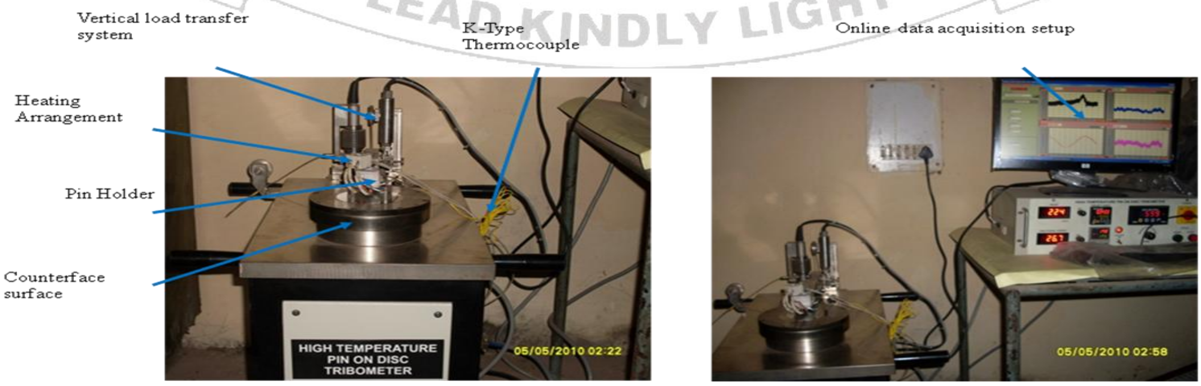

Fig-1: Experimental setup of pin on disc machine

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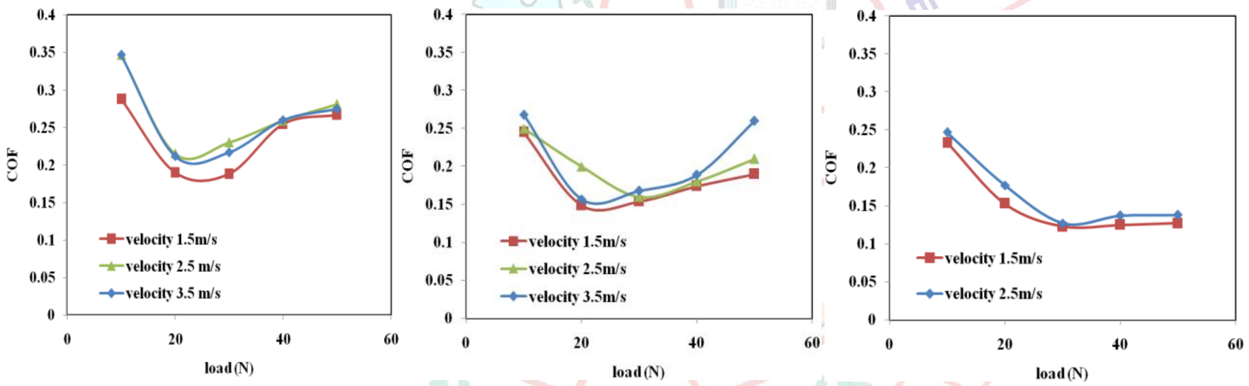
thermal conductivity of brass pin reduced the energy loss between them. The temperature of brass pin was constantly maintained at the stated temperature till the end of the wear test using temperature controller. Experiments are carried out with temperature at 50^0C and 100^0C using five several loads (10N, 20N, 30N, 40N, & 50N) for 10min.

3. RESULT AND DISCUSSION

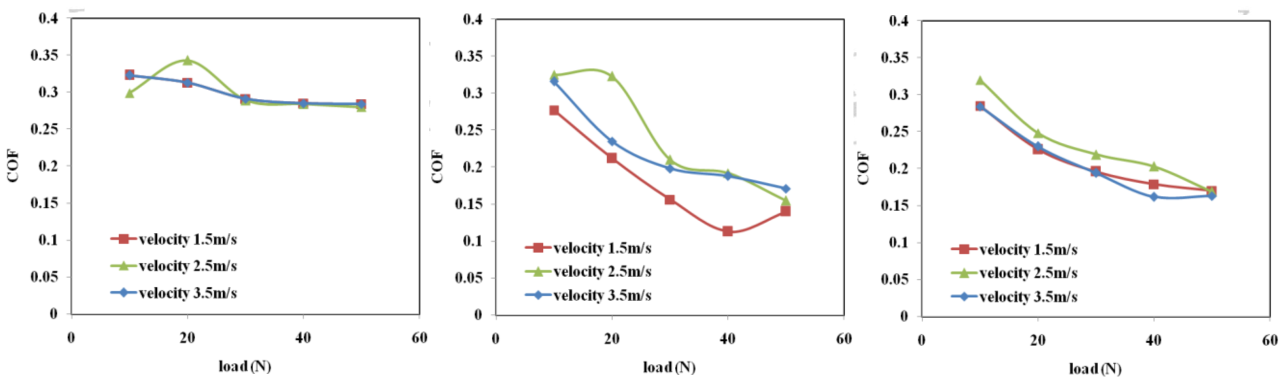
Result of experiment in dry sliding condition is shown in Fig. 2(a) that in dry condition the COF is high at low load and increases with increasing load. It is due to, at low load actual metal to metal contact take place so COF is high in 10N and in load 20N the oxide film formed and third body abrasion developed which reduces the COF. Again load increases, the oxide film dose not support the load then oxide layer breaks and reduces the metal to metal contact surfaces increased the COF. The co-efficient of friction is observed to be high at low load and then decreased and again increased. Because by observation, the friction force is high at the starting of first 5 seconds and it fluctuated for some time and thereafter maintained steady-state behaviour with few fluctuations.

The increased normal load (fig. 2(a)&(b)) decreased the lubricant viscosity which reduces film thickness. At low load the lubrication film thickness is very high so it resists shear stress. For this more friction force will produced and co-efficient of friction is high. According to that after few cycle film thickness get reduced and co-efficient of friction also reduced. But again increased load asperity-asperity contact height is reduced and real contact area take place and co-efficient of friction again increased.



(a) (b) (c)

Fig-2: Variation of COF with load for (a) dry, (b) micro lubrication & (c) nano lubrication condition at room temperature.



(a) (b) (c)

Fig-3: Variation of COF with load for (a) dry at 500 C, (b) nano lubrication at 500 C& (c) nano lubrication condition at 1000 C temperatures.

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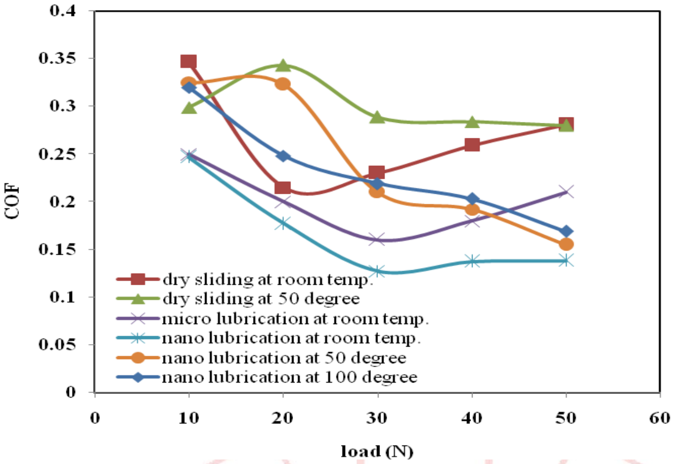

Fig-4: Variation of COF with load for different conditions at 2.5 m/s sliding velocity.

The use of micro lubricant the COF decreases and slightly decreases for nano lubricant as in fig. 3(b)&(c) respectively. By applying lubrication, it is shown that the co-efficient of friction at low load is very high then reduced and increased with increasing load. In lubrication system the sliding surfaces are separated by the film of lubricant with graphite, and normal load is

supported by this film. At very high load in the film increases the viscosity of the lubricant which tends to increase the film thickness. At low load the lubrication film thickness is high. However the required

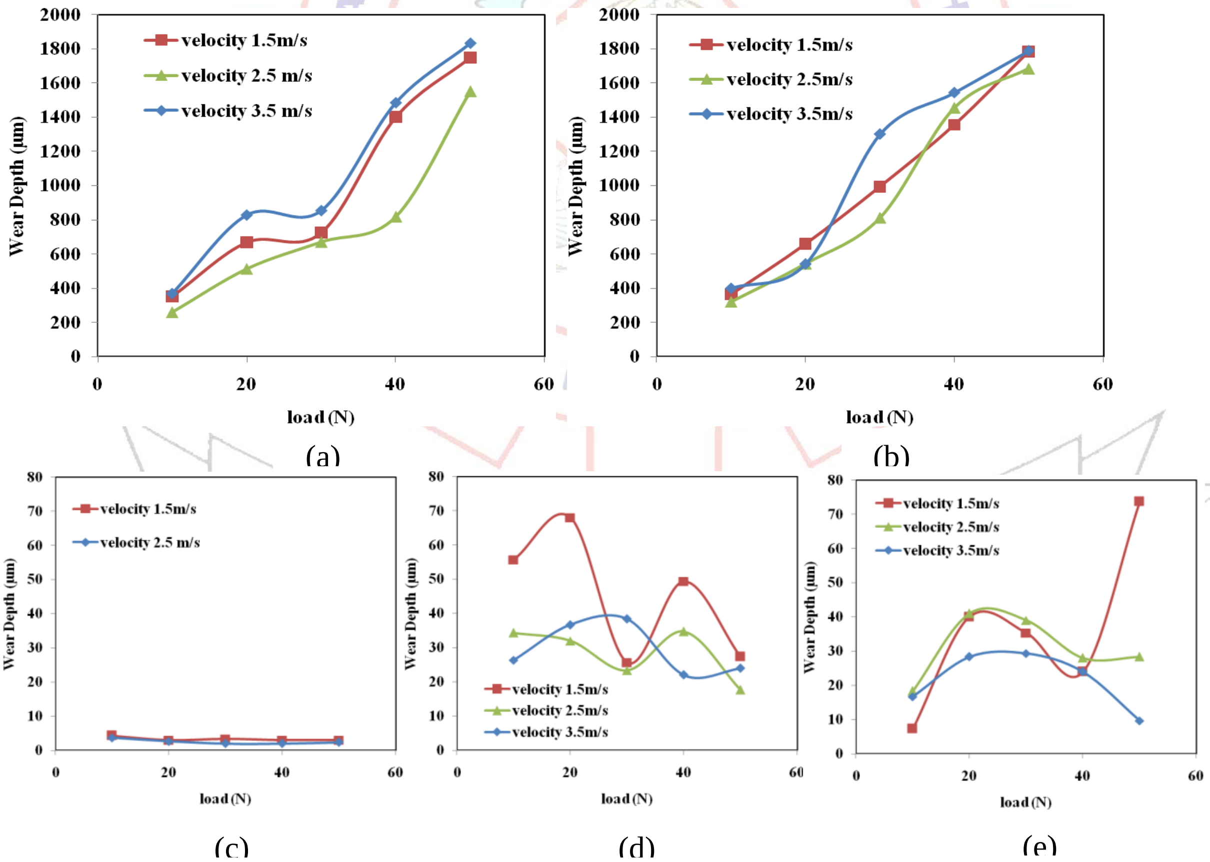

Fig-5: Variation of wear depth with load for (a) dry sliding at room temp, (b) dry at 50^0 C, (c) nano lubrication at room temp, (d) nano lubrication at 50^0 C & (e) nano lubrication condition at 100^0 C temperatures.

shear stress to deform the viscous layer is high leads co-

efficient of friction is very high. Again increasing load the contact region expands and film thickness is reduced but real area of contact does not take place results the minimize contact. This leads to low coefficient of friction. At high load, the lubricant film zout from the contact zone results more metal to metal contact. This results the higher the coefficient of friction and wear. Because of temperature of friction pair, it causes the reduction of viscosity of entrapped base oil results easy flow out the contact zone. At higher load, there is no realization of lubrication between the tribo-pair. Also at higher velocities the COF is more for all the above cases.

Figure 3(a) shows the variation of COF with load for dry lubrication at 50^0, (b) shows the variations for nano lubrication at 50^0 and (c) shows for nano lubrication at 100^0 temperature. As the temperature increases the viscosity decreases and the COF decreases and further increase to 100^0 effects a little on COF. For all the cases increase in velocity increase COF for lowed load and almost same for higher load.

Variation of COF with load for different conditions at 2.5 m/s sliding velocity is shown in fig. 4. For increase in load COF decreasing and lowest for nano lubrication at room temperature then micro lubricant at room temperature and then dry sliding at room temperature. As the temperature increase to 50^0 COF increases. Further increase in temperature to 100^0 for nano lubrication does not affect much on the COF.

The wear depth increases with increasing load, The wear depth reduces with increase in sliding speed in the region of lower speeds as shown in fig.5 and the transfer rate from brass to steel decreases correspondingly, so that the wear depth of brass decreases. Increased sliding speed increased the strain rate which has also increased flow strength. The increase in the flow strength will be reduced due to the true area of contact and thus wear depth decreased. On the contrary, the increase in sliding speed causes the temperatures to rise; thus the shear strength of the brass drops, and the wear rate increases with increasing sliding speed.

At high load, the lubricant film out from the contact zone results more metal to metal contact. This results the higher the coefficient of friction and wear. Because of temperature of friction pair, it causes the reduction of viscosity of entrapped base oil results easy flow out the contact zone. At higher load, there is no realization of lubrication between the tribo-pair.

Variation of wear with load for different conditions at 2.5 m/s sliding velocity is shown in fig. 6. For increase in load wear remains almost same and lowest for nano lubrication at room temperature then nano lubricant at50^0 and then nano lubricant at100^0. As the temperature increase to 50^0 wear increases. Further increase in temperature to 100^0 for nano lubrication does not affect much on the COF.

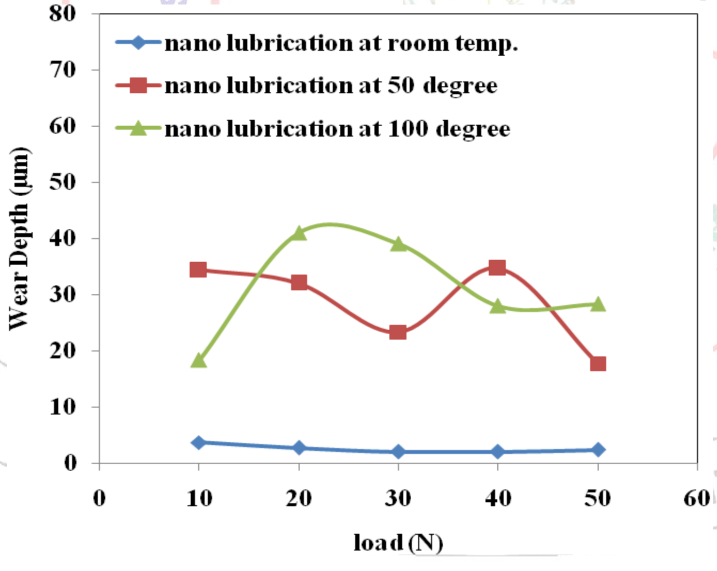

Fig-6: Variation of wear depth with load for different temperature conditions using nano lubricant at 2.5 m/s sliding velocity.

4. CONCLUSION

- Wear depth (micron) is directly proportional to load in both dry condition and dry condition with heating temperature 50^0C.
- The coefficient friction and wear depth both are exhibiting similar trend with increase in sliding

velocity at dry sliding condition and lubricated condition.

- In dry condition at temperatures (50^0C) the coefficient of friction increases with increasing load, where as in lubricated condition at temperatures (50^0C) the coefficient of friction decreases with increasing load.
- Variation of wear depth is marginally increasing with load in lubricated condition at temperature 50^0C.

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