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Tribological Behaviour of Alumina As A Lubricant Additive

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ABSTRACT

This study has been undertaken to investigate the tribological behaviour of a lubricant by adding Alumina as an additive. Studies have shown that lubricants with nano additives are found to have better tribological properties such as improved resistance to friction, good anti-wear characteristics, increased load carrying capacity and good heat absorbing capacity. Aluminium Oxide nano powder is added to the lubricant as an objective to reduce the friction and wear on the engine parts. Focus of this study is to improve the frictional resistance and wear resistance by adding nano powders to the lubricant, hence thereby increasing the efficiency of the machine. The frictional coefficient and wear rate on cast iron work piece is calculated, when Alumina is used as lubricant additive. In this study, Pin-on-Disc testing method was used for tribological characterization. Sliding wear tests for different number of specimens was conducted by using a pin-on-disc machine using lubricant added with 5% (weight) Alumina. Specimens of size 6 mm diameter and 30 mm length were cut from the cast samples, and then machined. The sliding wear characteristics of the cast iron specimen was determined by varying the parameters such as speed, time and load, throughout for all the experiments using the pin-on-disc test apparatus. From the experiment, the percentage of change in the wear for a cast iron specimen by adding 5% (weight) to the castor oil was determined as 0.0956 %. This implies that the wear rate is decreased by 0.0956 %, when the Alumina nano powder is added to the castor oil. As the nano particles are added to the castor oil, the wear rate decreased when compared without adding the lubricant. Hence, indirectly the efficiency of a mating part increases by increasing the wear resistance.

Keywords:— *Lubricants, Additive, Alumina, Tribology.*

I. Introduction

The engine is the heart of the automobile and then hydraulic control system is the vein and muscle. The average car uses 15% of its fuel consumption overcoming friction within the engine and gearbox and this decreases the efficiency of the engine. An internal combustion engine is comprised of dozens of moving parts. Without proper oiling, these parts run against each other with tremendous speed, creating friction which then leads to heat. This heat can wear the mechanical parts of an engine and lead to bad performance under the hood. Worn parts due to friction cause havoc with gas mileage and emissions since the engine is pushed to work harder. Wear on the engine's vehicle is a primary known cause of less efficient burning of fuel.

The subject Tribology generally deals with technology of lubrication, friction, and wears prevention of surfaces having relative motion under load. The word tribology was first reported in a landmark report by Jost (1966). The word is derived from the Greek word tribos meaning rubbing, so the literal translation would be "the science of rubbing". Its popular English language equivalent is friction and wear or lubrication science, alternatively used [6]. Tribology is the science of interacting surface in relative motion. It includes the study and applications of principles of friction, lubrication and wear. The reduction of wear depends on the conditions such as load, geometry, relative surface motion, sliding speed, surface roughness, lubrications and vibrations. There are several experiments for testing friction and wear in which one of the main testing methods is pin-on-disc configuration [7].

Alumina ceramics like other Ceramics are brittle, and the prevailing mechanism of their wear is abrasion by micro fracture mode, which is characterized by a formation of cracks in the subsurface regions surrounding the wear groove. It is different from metals wearing mainly by adhesive mechanism when a strong metallic bonding forms between the contacting micro asperities and from polymers dominating wear mechanism of which is abrasion caused by plowing and cutting actions. Tribological characteristics and mechanism of wear of alumina were studied by S. Jahanmir and X. Dong [8]. The authors showed that the tribological performance of alumina is controlled by one of the four different mechanisms: tribochemical reaction, plastic flow and plowing, micro fracture and formation of glassy surface film. It was also concluded that increase of the fracture toughness, modification of the boundary phase composition and lowering the coefficient of friction will improve the tribological performance of alumina.

II. Literature Review

Vu Nguyen–Anh Le and Jau–Wen Lin (2017) investigated the influence of aluminum nanoparticles, oleic acid as dispersants, and rotational speed on the tribological behavior of a lubricant. The experiments are performed on a pin- on-disc tribotester at a normal force of 90 N and a rotational speed ranging from 150 rpm to 600 rpm. Both the aluminum nanoparticles and oleic acid are in concentrations from 0 to 1 wt% and are added to the SN150 base oil. The results revealed that the addition of aluminum nanoparticles and oleic acid to the base oil will lead to significant friction reduction and anti-wear properties. The coefficient of friction (COF) and wear rate decreased after an increase in the concentration of nanoparticles and oleic acid, and an optimum concentration level was exhibited in which both COF and wear-rate were lowest [1].

D.-H. Hwang and K.-H. Zum Ghar(2003) investigated the tribological behavior of oil lubricated steel-alumina sliding pairs using a ball-on-disc tribometer at room temperature. Commercial bearing balls of 10 mm diameter were mated to the 99.7 % Al2O3 discs and additive free mineral oil was fed into the contact area. The sliding speed, the applied normal load and in addition the initial surface roughness of the Al2O3 disc were varied by different polishing and grinding procedures. The results showed that the surface roughness of the ceramic discs dominated the tribological behavior at the given experimental conditions where the sliding speed as well as the normal load showed less effect on the friction behavior but the amount of wear depended strongly on normal load. From the results it can be concluded that the improvement of the surface roughness and optimized surface machining, respectively, of the ceramic material can be essential to improve the tribological performance for boundary lubricated steel/ceramic sliding pairs [2].

Ajinkya S. Pisal and D S Chavan (2014) carried their experiment on Pin on Disc Tribometer and the tests were performed under wet conditions with varying load, speed and varying concentration of nanoparticles in engine oil. Base oil with CuO nanoparticles improved tribological properties in terms of load carrying capacity, anti-wear and friction reduction than the base oil without nanoparticles. The deposition of nanoparticles on the worn surface can decrease the shearing stress, and hence reduce friction and wear [3].

S. Baskar and G. Sriram (2014) investigated, the friction and wear behaviour of journal bearing material using a pin-on–disc test under wet conditions (Hydrodynamic lubrication) where the pin is Brass and the disc is EN31 hardened with three different lubricating oils i.e. Synthetic lubricating oil (SAE 20W40), chemically modified rapeseed oil, chemically modified rapeseed oil with nano CuO. Tests were carried out at maximum load and different sliding speeds. After the test chemically modified rapeseed oil with nano CuO has a lower friction coefficient and high wear resistance [4].

M. Anil Kumar and PNL Pavani (2017) investigated friction and wear behavior of so many materials as there is a need to study the undesirable effect observed in the performance and life of machinery components. The review was carried out to study the friction and wear behavior of different materials using Pin-On-Disc tribometer under wet and dry lubrication conditions. Dry lubrication is used for low and medium loads and to get lower wear rates and frictional forces, application of vegetable oils is preferable as they are anti-pollutant lubricants. Under maximum working conditions application of lubricant is not suggestible, where self-lubricating materials can be used [5].

III. PROBLEM DEFINITION

The engine oil which is being traditionally used since the invention of machineries is mainly used for reducing the friction and wear on moving parts leads had the disadvantage of forming oil sludges. Thus there was a need to develop a new type of engine oil which can overcome this drawback even at the conditions of extreme pressure. Finally researchers were laid open with an idea of dispersing nanoparticles in the engine oil. When the engine oil with dispersed nanoparticles were subjected to service conditions, it was observed that they performed better in reducing the friction, wear and lubrication, etc. [7]. Focus of this study is to improve the frictional resistance and wear resistance by adding nano powders to the lubricant, hence thereby increasing the efficiency of the machine. Aluminium Oxide nano powder is added to the lubricant as an objective to reduce the friction and wear on the engine parts. The frictional coefficient and wear rate on cast iron work piece is calculated, when Alumina is used as lubricant additive.

IV. RESEARCH METHODOLOGY

In this study, Pin-on-Disc testing method was used for tribological characterization. Sliding wear tests for different number of specimens was conducted by using a pin-on-disc machine using lubricant added with 5% (weight) Alumina. Specimens of size 6 mm diameter and 30 mm length were cut from the cast samples, and then machined. The sliding wear characteristics of the cast iron specimen was determined by varying the parameters such as speed, time and load, throughout for all the experiments using the pin on disc test apparatus.

4.1. Test Setup Pin On Disc (Pod) Wear Testing Machine

Tribological characteristics of a wide range of materials under conditions of various normal loads can be determined by the POD machine. A stationary pin mounted on a pin holder is brought into contact against a rotating disc at a specified speed. Pin slides in the presence of lubricating oil, introducing frictional force between the pin and disc (Figure 1).

4.1.1 Test Specimen

The typical pin specimen is cylindrical in shape. Typical cylindrical pin specimen diameter is 6mm, 8mm, 10 mm and length is 30 mm. The surface of the pin is finished because rough surfaces make wear measurement difficult. Material used for making pins for testing the disk material on which the pin slides.

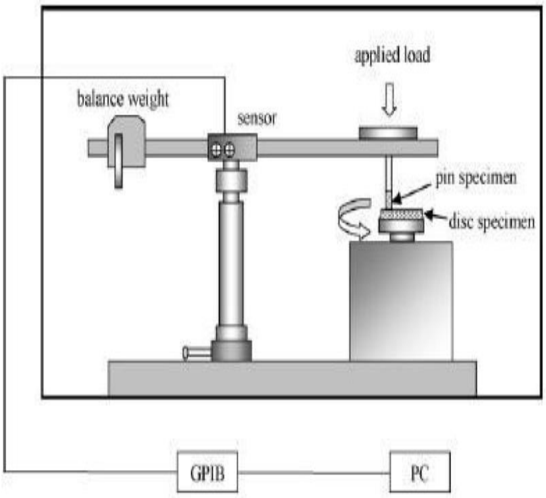

Figure 1: Pin-On Disk [4]

4.1.2 Test Parameters

The aim of the experimental plan is to find the important factors and the combination of factors influencing the wear process to achieve the minimum wear rate and Coefficient of Friction. The experiment is conducted with the aim of relating the influence of sliding speed, applied load and sliding distance. The amount of wear in any system will, in general, depend upon the number of system factors such as the applied load, machine characteristics, sliding speed, sliding distance, the environment, and the material properties. The following are the input parameters specified for the experimentation. The range of the parameters is shown in Table 1.

1. ***Normal Load:*** Values of the force in Newton's at the wearing contact.
2. ***Speed:*** The relative sliding speed between the contacting surfaces in metres per second.
3. ***Time:*** Running time of experiment in minutes.
4. ***Track Radius:*** The path generated is circle, so the specimen pin can be positioned over disc.

5. ***Flow Rate:*** Flow of oil on the disk. A constant flow of oil is maintained for this experimental study to achieve a film between the contacting surfaces. (Weather used lubricating oil)

Table 1: Range of Input Parameters for Experimentation

Parameter	Range
Normal Loads	9.81 N and 19.62 N
Speed	200 rpm – 220 rpm
Sliding Distance	691 m and 628 m (up to 700 m)
Running Time	8 min – 10 min

4.1.3 Output Parameters

In the experiment the parameters such as speed, time and load are kept constant throughout for all the experiments. The height loss due to friction is measured from the pin-on-disc tester and using this parameter, wear rate is calculated and other parameters like Coefficient of Friction, Frictional force, Sliding Distance, etc., are obtained correspondingly as mentioned below.

1. ***Wear Rate (mm^3/Nm):*** Material removal rate per unit parameter due to wear.
2. ***Frictional Force (N):*** Force exerted by a surface on a relative moving object across it.
3. ***Coefficient of Friction:*** A dimensional less quantity indicating the frictional force between the two relative bodies.
4. ***Sliding Distance:*** It is the linear distance travelled by the pin over the plate within given time interval if free from the tool holder. Sliding distance evaluates the wear rate. Sliding distance does not vary with load, time, flow rate etc. It varies only with speed.
5. ***Sliding Velocity:*** Sliding velocity denotes velocity with which the pin slides over the plate.

4.2. Experimental Setup

In this study, Pin-on-Disc testing method was used for tribological characterization. Sliding wear tests for different number of specimens was conducted by using a pin-on-disc machine using lubricant added with 5% (weight) Alumina. The pin was held against the counter face of a rotating disc (EN31 steel disc) with wear track diameter 100 mm (Figure 2). The pin was loaded against the disc through a dead weight loading system. The wear test for all specimens was conducted under the normal loads of 9.81 N and 19.86 N. Wear tests were carried out for a total sliding distance of approximately 700 m under similar conditions as discussed above.

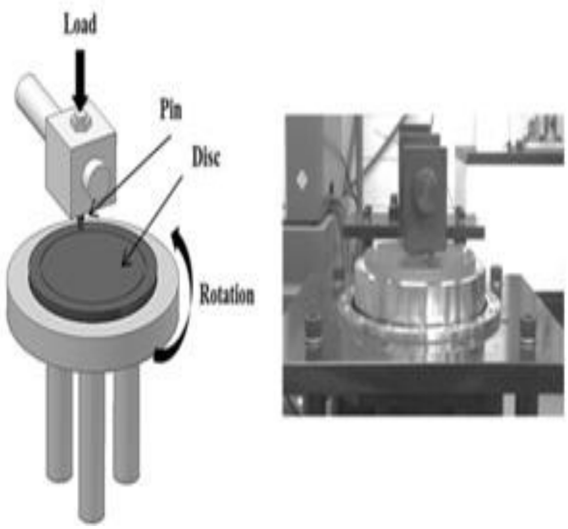

Figure 2: Parts of pin on disk ball tester

The pin samples were 30 mm in length and 6 mm in diameter. The surfaces of the pin samples were slides using emery paper (80 grit size) prior to test in order to ensure effective contact of fresh and flat surface with the steel disc. The samples and wear track were cleaned with acetone and weighed (up to an accuracy of 0.0001 gm using microbalance) prior to and after each test. The wear rate was calculated from the height loss technique and expressed in terms of wear volume loss per unit sliding distance.

Figure 3: Experimental Setup at Laboratory at NIT, Warangal

4.3. Experimental Procedure for Wear Test

Immediately prior to testing, and prior to measuring or weighing, clean and dry the specimens. Take care to remove all dirt and foreign matter from the specimens. Use non -chlorinated, non-film forming cleaning agents and solvents. Dry materials with open grains to remove all traces of the cleaning fluids may be entrapped in the material. Steel (ferromagnetic) specimens having residual magnetism should be demagnetized. Report the methods used for cleaning.

- Measure appropriate specimen dimensions to the nearest 2.5 µm or weigh the specimens to the nearest 0.0001 g.
- Insert the disk securely in the holding device so that the disk is fixed perpendicular (61°) to the axis of the resolution.
- Insert the pin specimen securely in its holder and, if necessary, adjust so that the specimen is perpendicular (61°) to the disk surface when in contact, in order to maintain the necessary contact conditions.
- Add the proper mass to the system lever or bale to develop the selected force pressing the pin against the disk.
- Start the motor and adjust the speed to the desired value while holding the pin specimen out of contact with the disk. Stop the motor.
- Set the revolution counter (or equivalent) to the desired number of revolutions.
- Begin the test with the specimens in contact under load. The test is stopped when the desired number of revolutions is achieved. Tests should not be interrupted or restarted.

- Remove the specimens and clean off any loose wear debris. Note the existence of features on or near the wear scar such as: protrusions, displaced metal, discoloration, micro-cracking, or spotting.
- Remeasure the specimen dimensions to the nearest 2.5 µm or reweigh the specimens to the nearest 0.0001 g, as appropriate.
- Repeat the test with additional specimens to obtain sufficient data for statistically significant results.

Initially, pin surface was made flat such that it will support the load over its entire cross-section called first stage. This was achieved by the surfaces of the pin sample ground using emery paper (80 grit size) prior to testing. The selected lubricant with 5% (weight percentage) Alumina in it is poured on the steel disc. The pin is made in contact with the disc and the disc is rotated with selected rpm and for selected time. Run-in-wear was performed in the next stage/ second stage. This stage avoids initial turbulent period associated with friction and wear curves.

Final stage/ third stage is the actual testing called constant/ steady state wear. This stage is the dynamic competition between material transfer processes (transfer of material from pin onto the disc and formation of wear debris and their subsequent removal). Before the test, both the pin and disc were cleaned with ethanol soaked cotton. Before the start of each experiment, precautionary steps were taken to make sure that the load was applied in normal direction.

4.4. Equations and Calculations

The wear measurements should be reported as the volume loss in cubic millimeters for the pin and disk, separately. The following equations were used for calculating volume losses when the pin has initially a spherical end shape of radius R and the disk is initially flat, under the conditions that only one of the two members wears significantly:

Pin volume loss (mm^3) = [π× {wear scar diameter (mm)}] / [64 ×sphere radius (mm)]

This is an approximate geometric relation that is correct to 1 % for (wear scar diameter/sphere radius) < 0.3, and is correct to 5 % for (wear scar diameter/ sphere radius) < 0.7. Calculation of wear volumes for pin shapes of other geometries use the appropriate geometric relations, recognizing that assumptions regarding wear of each member may be required to justify the assumed final geometry. The following equations were used for calculating the area and wear rate:

1. Area of the Specimen, $A = \pi r^2$

A= π× (6×10-3)2 = 1.1309×10-4 m2

2. Wear rate = (Volume loss) / (Sliding distance × load)

Where Volume loss = 4π×r3×h

h = height loss due to friction

3. Sliding distance = π×d×N

where d = wear track diameter

N = Speed of Rotation

V. Results and Discussion

The sliding wear characteristics of Cast Iron specimen with a mass of 1 kg, determined using Pin-on-Disc tribometer, and castor oil as the lubricant, with variable parameters is shown in Table 2. Specimens of size 6 mm diameter and 30 mm length were cut from the cast samples, and then machined. The contact surface of the cast sample (pin) was made flat so that it should be in contact with the rotating disk. The experiment was conducted initially without addition of Alumina using constant load, speed and running time. Later, Alumina was added to the lubricant and the test was repeated four times by varying one parameter during each test.

Tribological Test (1)

In this experiment, the speed is fixed with 220 rpm, with time of disc set to run for 10 minutes by putting 9.81 N weight and without adding Alumina to the lubricant. The pin length differences gives the height loss due to friction, using which wear rate is calculated.

Tribological Test (2)

In this experiment, the speed is fixed with 220 rpm, with time of disc set to run for 10 minutes by putting 9.81 N weight and adding 5 % (weight) of Alumina to the lubricant. The pin length differences gives the height loss due to friction, using which wear rate is calculated.

Tribological Test (3)

In this experiment, the speed is fixed with 220 rpm, with time of disc set to run for 8 minutes by putting 9.81 N weight and adding 5 % (weight) of Alumina to the lubricant. The pin length differences gives the height loss due to friction, using which wear rate is calculated.

Tribological Test (4)

In this experiment, the speed is fixed with 220 rpm, with time of disc set to run for 10 minutes by putting 19.62 N weight and adding 5 % (weight) of Alumina to the lubricant. The pin length differences gives the height loss due to friction, using which wear rate is calculated.

Tribological Test (5)

In this experiment, the speed is fixed with 200 rpm, with time of disc set to run for 10 minutes by putting 19.62 N weight and adding 5 % (weight) of Alumina to the lubricant. The pin length differences gives the height loss due to friction, using which wear rate is calculated.

Table 2: Wear Rate of Cast Iron specimen with variable parameters

Parameter	Wear Rate (m^2/N)
(1) Without Alumina: Load = 9.81 N Time = 10 Min Speed = 220 rpm	2.091×10 -10
(2) With 5% Alumina: Load = 9.81 N Time = 10 Min Speed = 220 rpm	2.009×10 -10
(3) With 5% Alumina: Load = 9.81 N Time = 8 Min Speed = 220 rpm	2.614×10^{-10}
(4) With 5% Alumina: Load = 19.62 N Time = 10 Min Speed = 220 rpm	1.04×10^{-10}
(5) With 5% Alumina: Load = 19.62 N Time = 10 Min Speed = 200 rpm	2.29×10^{-10}

VI. Conclusions

In this study, the wear behavior of cast iron was evaluated using pin-on-disc tribometer and focusing on the effect of Alumina as additive in the lubricant. From the experiment, the percentage of change in the wear for a cast iron specimen by adding 5% (weight) to the castor oil was determined as 0.0956 %. This implies that the wear rate is decreased by 0.0956 %, when the alumina nano powder is added to the castor oil. As the nano particles are added to the castor oil, the wear rate decreased when compared without adding the lubricant. Hence, indirectly the efficiency of a mating part increases by increasing the wear resistance.

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