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Nano Metal Powder Fluidized Lubrication, Investigation for Friction Reduction

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Abstract: As a lubricant, friction-reduction properties of base oil are enhanced by the addition of nanoparticles to a moderate concentration.Dispersing nanoparticles inside base oil, due to the base oil's high viscosity, is a very difficult work. The nanoparticles modified by oleic acid exhibited good dispersibility and stability in base oil. Base oil with nanoparticles increased tribological properties in terms of load carrying capacity, anti-wear and friction reduction that base oil without nanoparticles.
Keyword: Nano metal powder lubrication, wear.

I. INTRODUCTION

The word tribology was first reported in a landmark report by scientist Sir Jost in 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. The latter term is hardly all- inclusive. Dictionaries define tribology as the science and technology of interacting surfaces in relative motion and of related subjects and practices. Tribology is the art of applying operational analysis to problems of great economic significance, namely, reliability, maintenance, and wear of technical equipment, ranging from spacecraft to household appliances. Surface interactions in a tribological interface are highly complex, and their understanding requires knowledge of various disciplines including physics, chemistry, applied mathematics, solid mechanics, fluid mechanics, thermodynamics, heat transfer, materials science, rheology, lubrication, machine design, performance and reliability. It is only the name tribology that is relatively new, because interest in the constituent parts of tribology is older than recorded history. It is known that drills made during the Paleolithic period for drilling holes or producing fire were fitted with bearings made from antlers or bones, and potters' wheels or stones for grinding cereals, etc., clearly had a requirement for some form of bearings. A ball thrust bearing dated about AD 40 was found in Lake Nimi near Rome.

Fig. 1 Sources contributing to overall losses in an engine

A. Objective

1) To analyze the tribological behavior of CuO & Al_2O_3 (separately) nanoparticles as additives in SN-500 base oil and compare results with standard base oil without nanoparticles.
2) Determining the appropriate concentration of Nano particle to achieve better properties.
3) To study the tribological properties of piston and cylinder materials, to minimize the friction and wear of the material.
4) To fabricate the testing specimen in the form of cylindrical pin of piston material.
5) To test the specimens on pin-on-disc tribometer in order to find out tribological behavior, such as coefficient of friction and wear rate.

B. Problem Statement

Global economic development has boosted up the automobile market in India for Two/Four wheelers vehicles in last decade with a growth rate of 15-18 %. At the same time fuel prices are also increased in last five years. This has resulted in demand of fuel efficient vehicles. Scientists have focused to apply upgraded technology to improve the efficiency and performance of an automotive I.C. engine by way of numbers of options. By using MPFI Fuel injection system, selection of lightweight materials for vehicle components and Tribological application in design to reduced friction and wear through selection of appropriate lubricants etc. The knowledge of tribological factors is important to reduce friction losses, emission level & also to improve the fuel economy in an I.C. engine. Lubricants play a vital role in machine life and performance, reducing friction and wear and preventing component failure. Poor lubricant performance can cause significant energy and material losses. The already large global demand for lubricants is expected to continue growing in the future. Engine oils account for approximately half of this demand, and industrial lubricants represent the second-largest and fastest-growing segment by volume. Performance-enhancing additives are a vital part of today's modern lubricants. Due in part to projected growth in manufacturing activities worldwide, the lubricant market is in need of lower-cost and higher-performing additives that meet end- user performance specifications and environmental safety requirements.

II. METHODOLOGY

Comparative study of tribological behaviour of base oil SN-500 and base oil with CuO & Al_2O_3 nanoparticles separately as an additive with varying quantities, for wear and friction were carried out. In this experimental analysis of tribological behaviour of nano oils, Pin on Disk Tribotester, is used by selecting proper material. Readings for coefficient of friction vs. time, wear vs. time were noted down for 1000 RPM disk speed, load conditions of 10N, 30N and 50N. These loads were selected from bibliographic research. Optimum values from the above experiments can be used in actual practice.

III. LITERATURE REVIEW

A lots of research work has been reported on nanoparticles preparation and development. However, a few little works has been reported on nanoparticles used in tribology for friction reduction and anti-wear properties. A brief review of some selected references on various types and there an application of nanoparticles is presented below.

Y.Y. Wu et al. [1] examined tribological properties of lubricating oils an API-SF engine oil and base oil with CuO, TiO_2 and Nano-Diamond nanoparticles used as additives. Friction and wear experiments were performed by using reciprocating Tribotester. CuO added in standard oil exhibit good friction-reduction and anti-wear property. The additions of CuO nanoparticles in the API-SF engine oil & the base oil decreased the friction coefficient by 18.4 and 5.8% respectively, and reduced warn depth by 16.7 and 78.8% respectively as compared to the standard oils without CuO nano particles. The anti-wear mechanism is attributed to the deposition of CuO nano particles on the worn surface, which may decrease the shearing stress, thus improving the tribological properties.

R. Chou et al. [2] investigated the influence of addition of 20 nm diameter nickel nano particles on the tribological behaviour of synthetic oil (polyalphaolefin, PAO6). A TE53SLIM tribometer (block-on-ring configuration) for testing at medium loads and a four-ball machine (ASTM D2783) were used in this research. Wear surfaces were analysed by SEM and EDS. The study leads to the conclusion that the addition of nickel nano particles to PAO6 results in a decrease in friction and wear and an increase in the load-carrying capacity of base oil. This tribological behaviour is closely related to the deposition of nano particles on the rubbing surfaces. According to result and discussion it was concluded that all suspensions decreased the average friction coefficient and wear with respect to PAO6.

The friction reduction was between 7% and 30% and wear was decreased between 5% and 45%. The PAO6+0.5% Ni20 suspension showed the highest friction and wear reduction with regard to PAO6. The load–wear index for all studied suspensions is higher than that of the base oil, with increments between 3.4% and 30.8%.The analysis of the wear scar by SEM and EDS shows the nano particles deposition on the wear surfaces with an improvement of the tribological behaviour.

Ashkan Moosavian et al. (2016) [3] in this paper's study the effects of piston scuffing fault on engine performance and vibrations are investigated in an internal combustion (IC) engine ran under a specific test procedure. Three body abrasive wear mechanism was employed to produce piston scuffing fault it caused the engine performance to reduce significantly. According to Continuous wavelet transform (CWT) analysis ''dmey" wavelet, piston scuffing fault appeared in the scales of 7–14 (frequency band of 2.4–4.7 kHz) and more at the scale of 9 (frequency of 3.7 kHz).

P.C. Mishra et al. (2014) [4] in this paper's study the piston compression ring tribology and the theoretical and experimental works developed to analyse ring liner contact friction. Because of micro conjunction effect the friction is comparatively less in case of a rough liner 80 % Power Loss is in compression and power stroke together of total power loss in an engine cycle. Broad literature survey is carried out in the research area of piston compression ring to know about the simulation and experimental methods developed to study its performance.

Dr. D.V. Bhatt et al. (2013) [5] added Titanium dioxide and P25 additives to re-refined base oil and the friction and wear characteristics were examined at a constant applied load and rate of reciprocation using reciprocating pin-on-disk apparatus. From this investigation it was found that the nanoTiO2 particles addition to the base oil slightly reduced the coefficient of friction.

Ming Zhan et al. [6] developed SRV4 oscillating friction and wear tester to examine the tribological properties of blank PAO (Poly-alpha-olefin) and PAO containing CaCo3 nanoparticles. The friction test conducted in reciprocating "ball on mode". The results showed that CaCO3 nanoparticles can dramatically improve the load carrying capacity, as well as the anti-wear and friction-reduction properties of PAO base oil. In addition, higher applied load, moderate frequency, longer duration time, and lower temperatures are beneficial to the deposition of CaCO3 nanoparticles accumulating on rubbing surfaces. X-ray photoelectron spectroscopy (XPS) reveals a boundary film composed of CaCO3, CaO, iron oxide, and some organic compounds on the worn surfaces.

J.C. Sanchez-Lopez et al. [7] reported work reports the employment of metallic Nano particles (palladium and gold) with a mean particle size of 2.2nm surface-protected with tetra-alkyl-ammonium and alkanethiolate chains respectively, as lubricant additives. Dispersions of both types of Nano particles (5 wt. %) are prepared using tetra-butyl- ammonium acetate (TBA) and paraffin as base oils, respectively. The tribological properties are then evaluated by a ball-on-disk Tribotester at two different loads (7 and 15N) with excellent results.

Ming Zhan et al. [9] developed SRV4 oscillating friction and wear tester to examine the tribological properties of blank PAO (Poly-alpha-olefin) and PAO containing CaCo3 nanoparticles. The friction test conducted in reciprocating "ball on mode". The results showed that CaCO3 nanoparticles can dramatically improve the load carrying capacity, as well as the anti-wear and friction-reduction properties of PAO base oil.

IV. FUNDAMENTALS OF TRIBOLOGY

A. Friction

Friction can be defined as resistance to movement between any two surfaces in contact with each other. When friction occurs in machinery, it is not so desirable. It destroys the effectiveness of the equipment through wear, heat and shortened life. We overcome this friction by doing lubrication.

B. Types of Friction

There are several types of friction:

Dry friction resists relative lateral motion of two solid surfaces in contact. Dry friction is subdivided into static friction between non-moving surfaces, and kinetic friction between moving surfaces.

Fluid friction describes the friction between layers within a viscous fluid that are moving relative to each other.

Lubricated friction is a case of fluid friction where a fluid separates two solid surfaces.

Skin friction is a component of drag, the force resisting the motion of a solid body through a fluid.

Internal friction is the force resisting motion between the elements making up a solid material while it undergoes deformation

C. Wear

Wear can be defined as undesired removal of material due to mechanical action. It is poorly understood in the scientific sense. Types of Wear By a conventional method wear is divided into following main types:

1) Adhesive wear means damage resulting when two metallic bodies rub together without the deliberate presence of an abrasive agent.
2) Abrasive wear is characterized by damage to a surface by harder material introduced between two rubbing surfaces from outside. The severity of abrasive wear depends on size and angularity of abrasive particles and also the ratio between hardness of metal and the abrasive particles, more the tendency to wear.
3) Fatigue wear occurs due to cyclic stresses in rolling and sliding contacts as in gears and rolling bearings.
4) Corrosive wear occurs due to corrosion. Rusting is a well-known example. The presence of moisture, oxygen availability and dusty conditions accelerate corrosive wear.

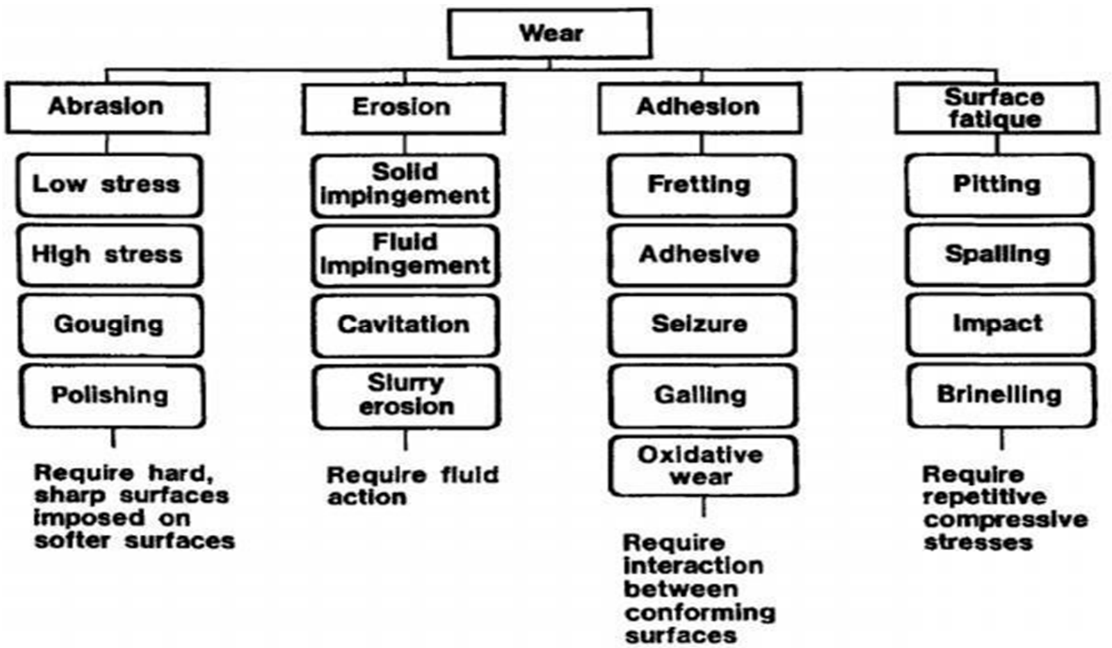


Fig.2 Basic Categories of Wear and Modes of Wear

V. IMPROVE ENGINE PERFORMANCE THROUGH CERAMIC COATING

A. Introduction

Nano Energizer is a fuel saving product and technology is used in engine oil for smoother and quieter engine with extreme power, more efficiency, and better mileage and reduce engine noise. This fuel saving product is an engine restorer which restores any engine (new or old) 100% without opening the engine. The 20nm Nano Platinum- Ceramic layer contains Platinum coated Zirconium ceramic powder which when injected into the engine oil, gets plastered onto the engine walls and protects and restores the engine without opening it Nano Energizer is a ceramic platinum coating which lines engine surfaces. With this coating the efficiency of an Internal Combustion Engine can be increased**.** The ceramic material used for the engine coating needs to have a low thermal conductivity and a high temperature stability, matched with thermal expansion which then bonds with the metal of the engine. Nano Energizer forms a durable bond with engine's metal adding a high wear resistance and also corrosion resistance.

Higher Efficiency of The Engine is reflected in Improved Performance Such as:

- Reduced Fuel Consumption
- Increased Power Output
- Reduced Noise and Vibration
- Reduced Oil Burning
- Reduced Air Pollution

It comes in the form of a sachet that is added to the engine oil of any internal combustion engine such as: Bikes, Cars, Tractors, Trucks, and Lawnmower & Boats

B. How to Use It

The product contains precious metal coated nano-size Zirconium powders emulsified in mineral oil and when applied, simply add it to the engine through oil filler port. With Nano Energizer, the Zirconium nano powder will be brought by piston movement to all working surface of the engine during its running [3].

C. Nano Energizer

Reducing energy consumption through improved engine efficiency is constant pursuit of the whole world. A large class of modern ICE such as omnipotent gasoline engine works following the Theorem of Carnot Cycle. The heart of the Carnot Cycle theorem says that an IC Engine works because it transfers portion of the heat energy into mechanical work.

Further, the genius of the Carnot Cycle Theorem is that it gives the specific description for the efficiency of an engine, which is:

$$\eta = 1 - T_{low} / T_{high} \quad \text{Equation (1.1)}$$

Where: η is the efficiency of the engine T_{low} is the temperature of the cold reservoir. T_{high} is the temperature of the hot surface interpreting the above the Theorem one can consider that T_{high} is roughly related to the average working temperature inside the engine cylinder and T_{low} to the average temperature of the air discharged to the exhaust.

For an average gasoline engine, the average working temperature is 1050ºC and the exhaust temperature of 750ºC. According to Equation 1.1 gives the engine efficiency of 28.6% (1-750/1050).

Figure 3. Nano Energizer Untreated	Figure 4. Nano Energizer Treated
	

VI. PISTON PIN MATERIAL AND DISK

A. Classification of Piston Material

Normally piston materials can be classified as alloy materials. Aluminum alloy materials are most preferably used for engine piston. It can vary with material composition. Silicon percentage mostly varies with application.

B. Piston Pin

We have studied the tribological properties of piston and cylinder of two wheeler petrol engine. The material used for piston pin is Aluminum alloy. Following are the different Aluminum alloys available for the piston

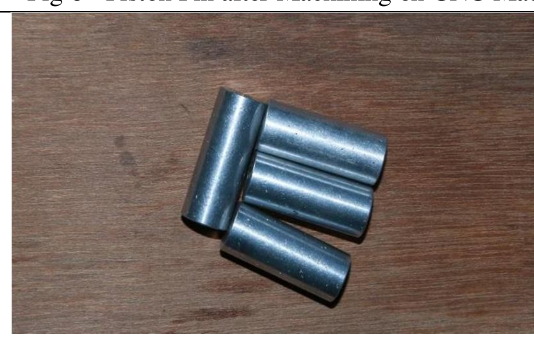
Piston alloy	Cu	Si	Mg	Fe	Ni	Al	SiC	Zr
JIS-AC8A	1	12	1	–	1	Balance	–	–
JIS-AC9B	1	19	1	–	1	Balance	–	–
AFP1	1	17	1	5.2	–	Balance	2	0.9

Table 1. Composition of piston alloys

Elements	Imported Piston [%]	Cast Piston [%]	Variation [%]
Si	19.86	19.29	-2.5
Fe	0.413	0.427	+3.3
Cu	0.80	0.774	-3.2
Mg	0.60	0.57	-3.3
Ni	0.81	0.794	-2.0
Ti	0.086	0.083	-3.2
Li	0.117	0.113	-3.7
Al	Bal	Bal	Bal

Table 2 – Variation in Composition after Casting of Piston

I took the material of piston with silicon 19%. Then by using casting process we made the piston pins. The piston pins made from casting process shows the following composition which is compared with imported piston. Following table shows the minor and has no any effect on piston properties. Variation in the composition of imported and cast piston.

Fig 5 - Piston Pin after Casting Process	Fig 6 - Piston Pin after Machining on CNC Machine
	

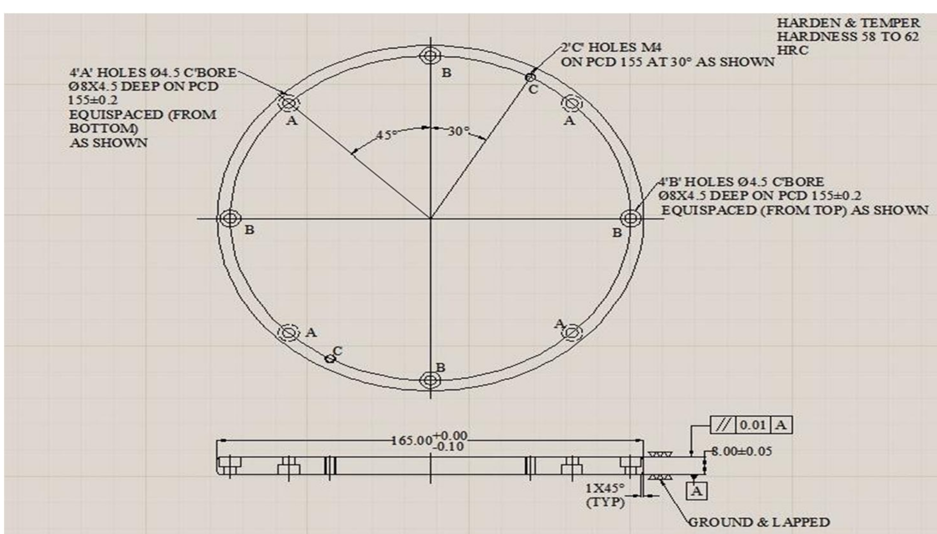


Figure 7: Disk Drawing

VII. EXPERIMENTAL ANALYSIS

For this experimental work, proper types of nanoparticles and base oil has been selected as follows.

A. Nanoparticles

Novel properties that differentiate nanoparticles from the bulk material typically develop at a critical length scale of under 100nm". The "novel properties" mentioned are entirely dependent on the fact that at the Nano-scale, the physics of nanoparticles mean that their properties are different from the properties of the bulk material. This makes the size of particles or the scale of its features the most important attribute of nanoparticles.

The friction-reduction and anti-wear behaviors are dependent on the characteristics of nanoparticles, such as size, shape, and concentration. The size of nanoparticles is mostly in the range of 2–120 nm. Nanoparticles are the simplest form of structures with sizes in the nm range. In principle any collection of atoms bonded together with a structural radius of < 100 nm can be considered nanoparticles.

For this research work I have short listed two type's nanoparticles i.e. Silicon Dioxide and Titanium Dioxide. The properties of these Nano particles are given below.

B. Copper Oxide (CuO)

Nanoparticles	Properties	
Copper Oxide (CuO)	Purity	>99.5%
	Form	Nano powder
	Avg. particle size	30-50 nm
	Bulk density	0.79 g/cm^3
	Particle shape	Spherical

Table 3. Properties of Copper Oxide Nanoparticles

Copper nanoparticles deposit uniformly on the surface and forming an auto- reconditioning film. The copper film has good tribological and micro mechanical properties. The forming mechanism of the auto-reconditioning film can be described that the copper nanoparticles deposit on the worn surfaces and form the iron-copper alloy film with lower hardness and shear strength, which has better friction-reducing, anti-wear and surface-optimizing behaviors. Copper oxide material is having good friction reduction, wear resistance, high thermal and electrical conductivity property.

C. Aluminium Oxide (Al2O3)

Nanoparticles	Properties	
Aluminium Oxide (Al2O3)	Purity	>99.5%
	Form	Nano powder
	Avg. particle size	30-50 nm
	Bulk density	1.5 g/cm^3
	Particle shape	Spherical

Table 4. Properties of Aluminium Oxide Nanoparticles

Also Al2O3 has good lubrication and thermal conductivity property.

D. Base Oil

The selection of a synthetic oil to examine the influence of metallic nanoparticles is mainly based on its superior rheological properties related to mineral oils. Paraffin based SN-500 base oil was selected as the base oil, as it is considered amongst the more promising synthetic lubricants used for common purposes. This selection is also based on the element that SN-500 base oil is used in industrial bearing oils, hydraulic oils, and aviation lubricants, heat transfer fluids, drilling fluids, dielectric fluids and greases. The SN-500 base oil properties are listed in Table 5.

PROPERTY	Range
Viscosity Kin., @40°C (cSt)	101 mm^2/s
Viscosity Kin., @100°C(cSt)	10.5 mm^2/s
Viscosity Index	95
Density @ 40°C	864-875 kg/m^3
Flash Point (°C)	240
Pour Point(°C)	-6
TAN (Mg KOH/gr)	<0.002
Carbon Residue (%Wt)	0.12
Color	1.5

Table 5. Properties of SN-500 Base oil

E. Paraffinic Base Oil Advantages

Property	Lubricating Benefit
Greater oxidation resistance	Operate at higher temperatures. Last longer- longer lubrication intervals. Less carbon, sludge, varnish and oil thickening from oxidation products.
Better lubricity and higher film strength	Less wear, friction and energy used
Higher natural viscosity index	Offers more lubrication protection over a wide temperature range - thins less at higher temperatures and thickens less at lower temperatures
More compatible with seals and hose	Longer seal and hose life. Less oil leakage

Table 6. Advantages of base oil

F. Pin on Disk Friction & Wear Testing Machine

The Pin on Disk Friction & Wear Testing Machine designed and developed, which is used to conduct trials. This machine is primarily intended for determining the tribological characteristics of wide range of materials under conditions of various normal loads & temperatures (optional). A stationary pin mounted on a pin holder is brought into contact against a rotating disk at a specified speed as the pin is sliding, resulting frictional force acting between the pin and disk are measured by arresting the deflecting pin holder against a load cell. Both normal load and speed can be set as desired.

G. Specimens

Following table shows that properties of Pin and Disk specimen which were used in pin on disk Tribotester for wear and friction testing.

Specimens	Material
Disc	Grey Cast Iron, hardness=130-180BHN, d=165 mm, t=8mm, E=66- 157GPa, ν=0.26
Pins	Aluminium alloy hardness=100-150BHN, d=12 mm, L= 30mm, E=73GPa, ν=0.33

Table .7 Properties of disk and pins

H. Pin on Disk Friction & Wear Testing Machine

The Pin on Disk Friction & Wear Testing Machine designed and developed by Ducom, which is used to conduct trials. This machine is primarily intended for determining the tribological characteristics of wide range of materials under conditions of various normal loads & temperatures (optional). A stationary pin mounted on a pin holder is brought into contact against a rotating disk at a specified speed as the pin is sliding, resulting frictional force acting between the pin and disk are measured by arresting the deflecting pin holder against a load cell. Both normal load and speed can be set as desired.

I. Technical Specifications

1) Normal load range – up to 200N
2) Wear measurement range – 0-4mm with tare facility
3) Maximum speed – 2000rpm
4) Test speed – 1000 rpm
5) Preset timer range – up to 99:59:59
6) Wear disk diameter and thickness –165mm and 8mm
7) Wear disk track diameter - 50 mm
8) Specimen pin diameter – 12mm
9) Pin length - 30mm 10.Sliding Velocity – 5 m/s

Fig. 8 Pin on Disk Tribometer including disk & pin.

J. Experimental Test Procedures

The tribological performances of lubricant were evaluated on Pin on disk Tribotester. All tests were carried on pin on disk Tribotester set for pure sliding contact with pin on disk configuration at ambient air with relative humidity between 40% to 50% and temperature at 30-35°C. Test pins will run against a counter face of disk which is mirror polished. In an experiment total eight numbers of samples were examined. The test parameter sliding speed of disk (1000rpm) and wear track radius (50mm) was remain constant at all test. Under these conditions, 10N, 30N and 50N loads were applied on disk though pin and analyse the parameter like wear in micron and coefficient of friction with help of computerized data acquisition system. Total twenty seven numbers of tests with 10 minute time period were performed.Optimum percentage of nano particle concentration (for particular load) was found for which friction and wear was less.

K. Test Setup

This apparatus, figure 4.5, is model of Pin on Disk Tribometer working at very low rpm, at constant sliding velocity and fixed radius of wear circle. This apparatus can be used in lab to perform wear testing of given metal and study the effect of lubrication of different lubricants on that particular metal under different loading conditions. The specific wear rate is calculated, the specific wear rate helps in determining wear resistance provided by the metal under running conditions.

Fig. 9 Test Setup "Pin on Disk Tribometer"

The setup consists of a frame, ring arrangement, pin rod (Aluminium Alloy) and metal discs (Grey Cast Iron) supported on a board. The disk is rotated by a motor, with 1000 rpm; the weights (Max 200N) were applied on the pin by placing the weights on the pan, to generate a wear pattern on the surface of the disc. For lubrication AC motor is used. Also during testing filters from suction line of pump and from inlet line of tank were removed. This was done for avoiding clogging of nano particles inside the filter.

L. Test Procedure

Steps to be followed in order to conduct the experiment are:-

1) Place the test metal disk on motor.
2) Place the pin over the disc.
3) Measure the radius of wear circle made by pin on the disc
4) Initially run the motor at full speed and ON the range meter.
5) Make the readings on control panel zero with knobs.
6) Place the weights in the pan and start the lubrication oil motor and then start rotating disc motor.
7) Observe the wear pattern on disk made by pin.

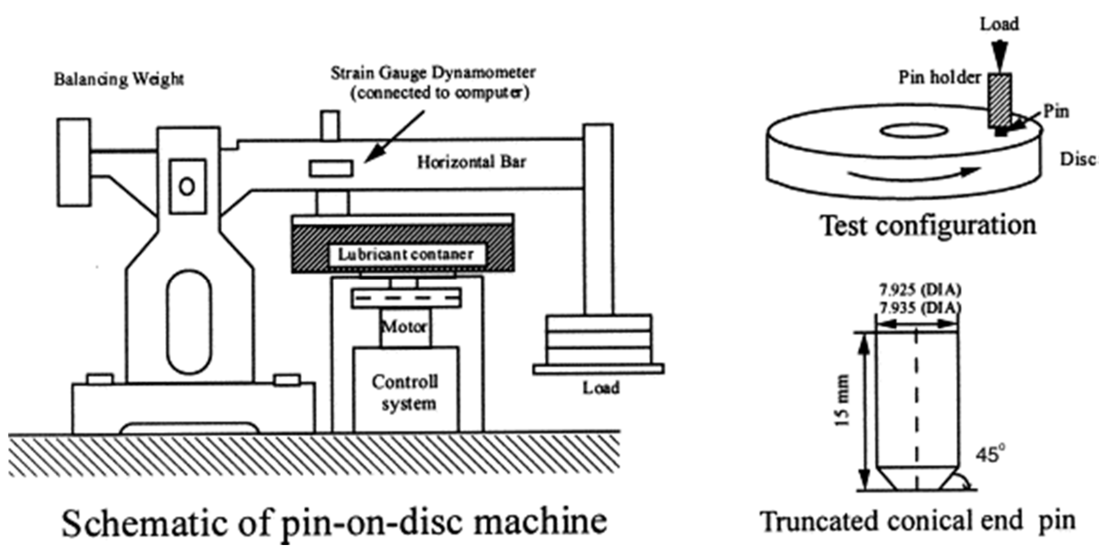


Fig. 10 Schematic Diagram of Pin on Disk Tribometer

VIII. DISCUSSION OF RESULTS

A. *Friction Reduction Properties*

In order to confirm the repeatability of experimental data, the friction coefficient was measured in triplicate using the pin on disk tribotester under 10N, 30N and 50N load conditions at 10 minute with concentration of particles constant for respective tests. The friction coefficients of SN-500 base oil without nanoparticles are displayed in fig. 8, which show a similar trend for different experimental results, and a maximum standard deviation of 0.198, 0.120 and 0.100 with respect to 10N, 30N and 50N load conditions among all sets of test data.

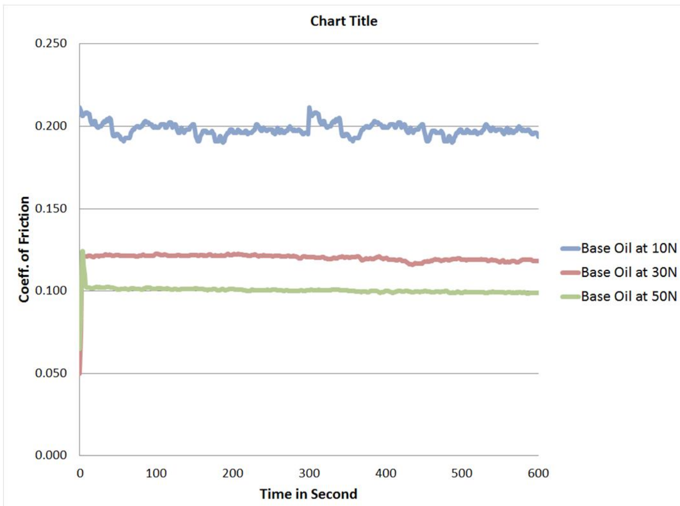


Fig.11 Friction coefficient with SN-500 base oil without nanoparticles

The friction coefficients of the SN-500 base oil with and without nanoparticles are shown in fig. 9 the x-coordinate shows the time elapse from start to end of single test. The coefficient of friction of SN-500 base oil containing nanoparticles, i.e. CuO & Al2O3 (separately) is slightly lower than those of SN-500 base oil without nanoparticles. In addition, CuO exhibits lower coefficient of friction than the other Al2O3 nanoparticles. It may note that in fig 9 concentration of nanoparticles samples are 0.1%.

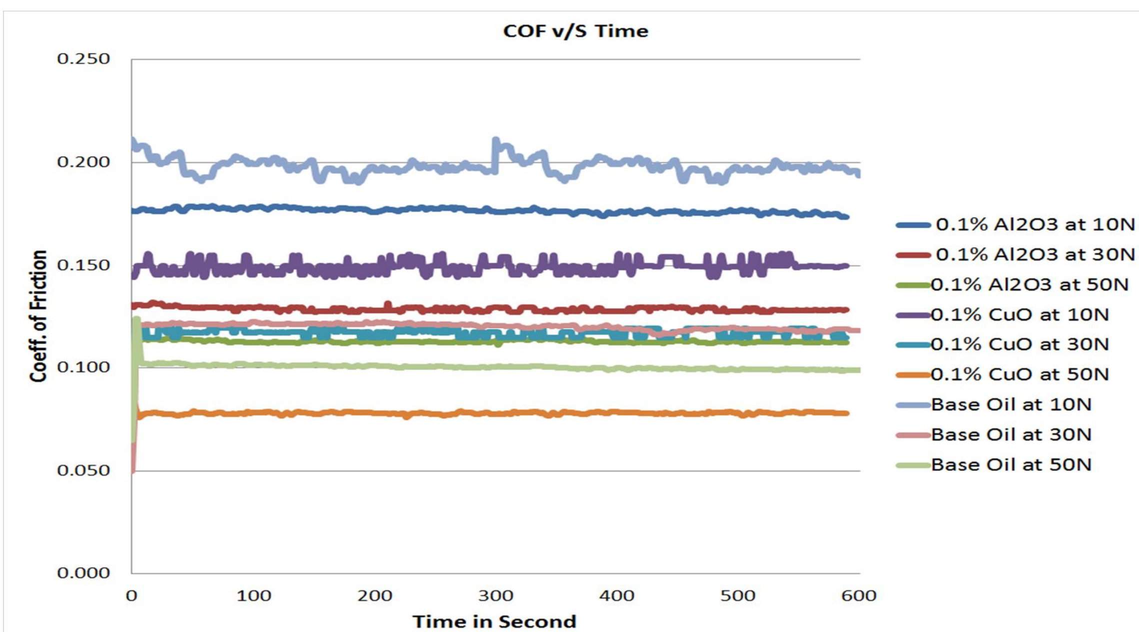


Fig.12 Coefficient of Friction of SN-500 Base Oil with and without Nanoparticles at 0.1% Conc.

B. Anti-wear Properties

The anti-wear properties are examined according to the results in form of graph from computerized data acquisition system. The wear in microns of SN-500 base oil without nanoparticles are displayed in fig. 10, which show a similar trend for different experimental values, and a maximum standard deviation of 10.40, 26.24 and 38.86 with respect to 10N, 30N and 50N load conditions among all sets of test data.

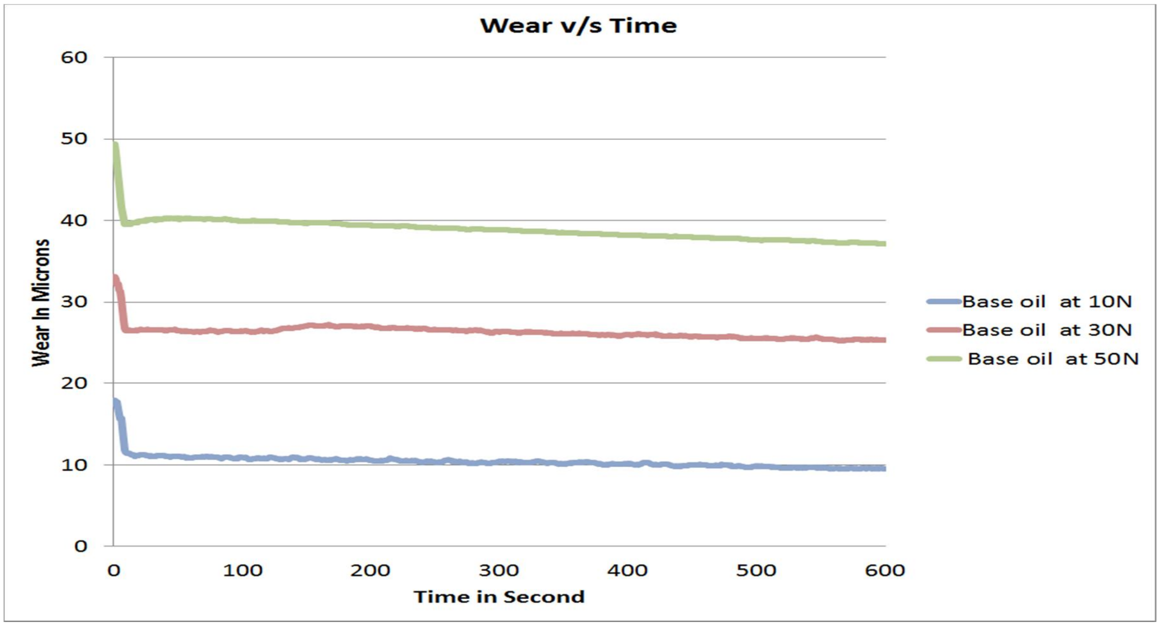


Fig.13 Wear in micron versus Time in second with SN-500 base oil without nanoparticles.

C. Effect of Load

The effects of load acting on two parameters i.e. wear and friction, so analysis of wear and coefficient of friction with respect to load explained below.

Load verses Wear

In this fig shows that graph of load in Newton on X-coordinate and wear in micron on Y- coordinates. At the same of 10N, 30N and 50N load conditions and % of particle concentration remains constant with respective tests.

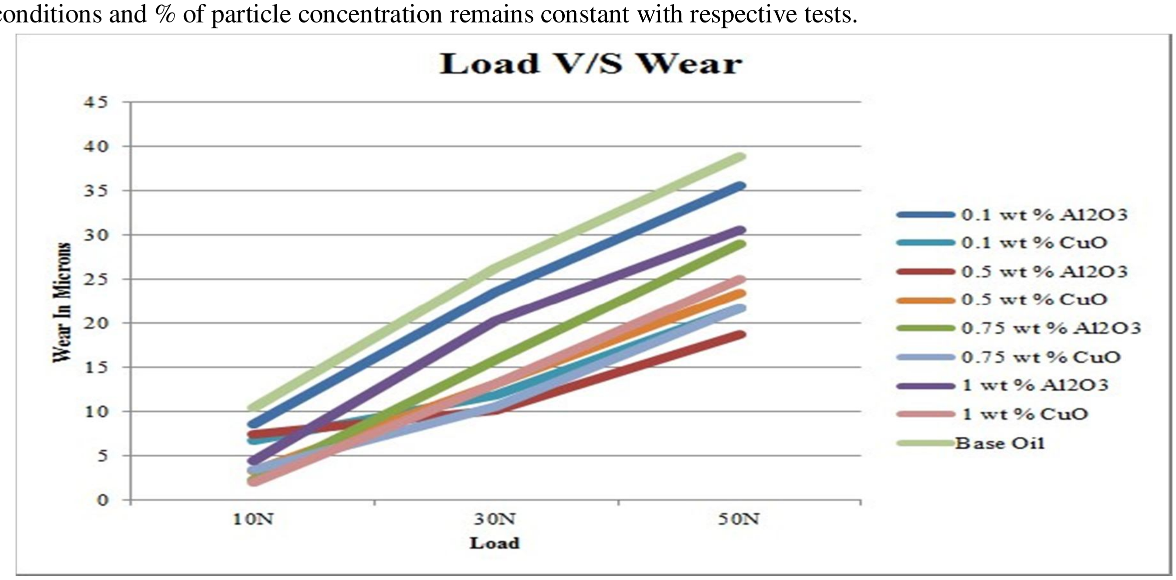


Fig.14 Base Oil with and without Nanoparticles at 0.1%, 0.5%, 0.75%, 1% Conc.

Fig.11 shows wear in micron verses load in Newton with nanoparticle concentration of 0.1%, 0.5%, 0.75% and 1% respectively.
In above figure, it shows that as the load increases Al_2O_3 nanoparticles with 0.5% concentration, shows less wear than that of SN-500 base oil without nanoparticles. In same figure it is shown that CuO nanoparticles reduces wear with respect to Al_2O_3 nanoparticles sample and SN-500 base oil without nanoparticles at 0.1% and 0.75% particle concentration respectively. Moreover, the particle concentration is 0.5% and load gradually increases then Al_2O_3 nanoparticles acts as third body and reduces wear.
Hence as the load increases then nanoparticles reduces wear and improve load bearing capacity. From the above observations of graphs, the conclusion can be extracted as when the nanoparticles are used as lubricant additives, the formation of transfer film onto the pin surface which reduce pin wear as compared with pure SN-500 Base oil. This layer appears thicker and more homogeneous in case of Al_2O_3 nanoparticles. This agglomerated materials acts protective layer of the surfaces avoiding direct contact between asperities.

D. Effect of concentration

For analyzing effect of particle concentration we can take value i.e. % of particle concentration verses friction as well as wear as shown in below figures. For this analysis we can take constant loads at 10N, 30N and 50N respectively.

Friction analysis

In this analysis, graphs taken at the load is constant and % of particle concentration varies on X-coordinate.
Figure 7.12 shows the coefficient of friction for all nanoparticle concentrations as regards SN-500 Base oil. For analysis purpose load of 10N is kept constant. The nanoparticles concentration is varied from 0.1 wt. %, 0.5 wt. %, 0.75 wt. % and 1 wt. %. The favorable results were occurs at nanoparticles concentration of 1 wt. % (CuO nanoparticles) at 10N load, 1 wt. % (Al_2O_3 nanoparticles) at 10N load. Hence Al_2O_3 nanoparticles have high coefficient of friction and CuO nanoparticles have low coefficient of friction. This behavior is because CuO nanoparticles act as a third body and present between pin and disk to produce rolling effect. Whereas Al_2O_3 nanoparticles tend to 3 body wear means that they provide rubbing action between pin and disk. Also the nature of graph shows that, for 0.1 wt. % concentration of nanoparticles, coefficient of friction is less as compared to 0.5 wt. % concentration. Further as nanoparticle concentration increases coefficient of friction reduces due to rolling effect of nanoparticles, as nanoparticles are spherical in shape.

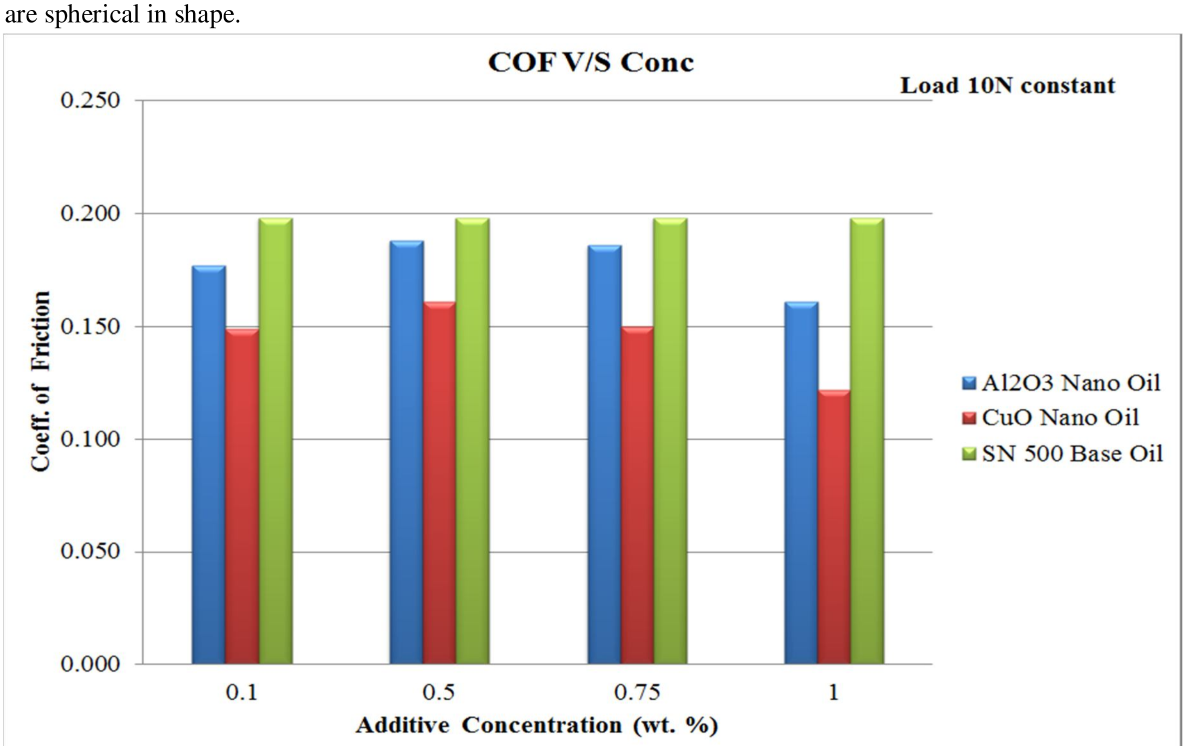


Fig. 15 COF V/S Nanoparticle Concentration at 10N Constant Load

E. Role of Nanoparticles in Lubricating Oil

Nano Polishing Effect

The additional nanoparticles changed the contact conditions for pin vs. disk and effectively reduced the friction force. Due to the abrasiveness of the hard nanoparticles, also a polishing effect on the worn surfaces could be expected. The worn surfaces of the pin without nanoparticles are normally rougher under higher loading conditions because of more serious surface damage. However, it is interesting to note that the roughness of the worn surfaces filled with nanoparticles remained stable, which is in agreement with the size of nanoparticles used in this study.

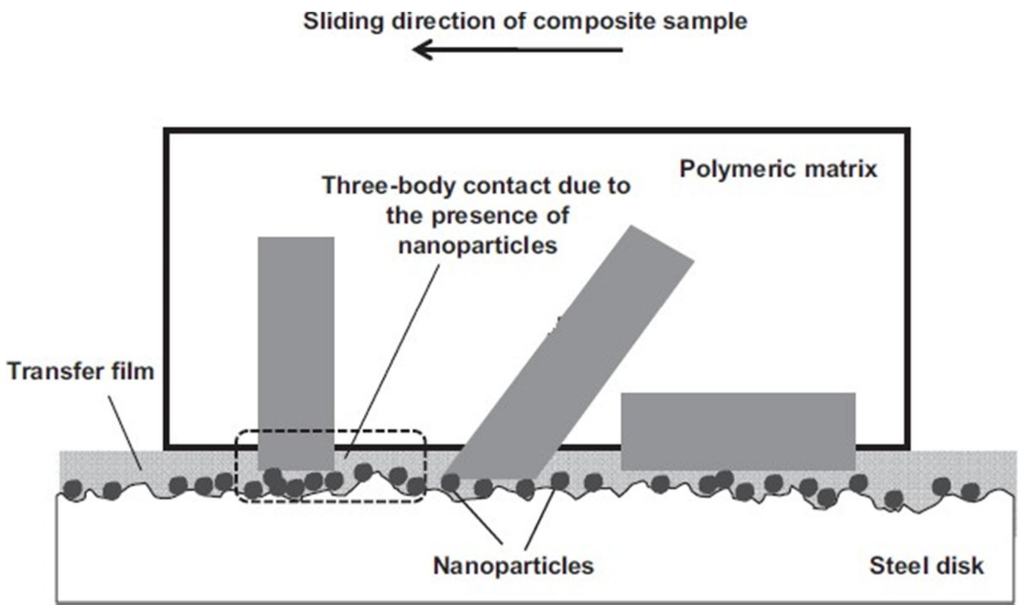


Fig.16 Nano Polishing Effect with Three Body Contact

Therefore, there are two competitive effects of nanoparticles on the wear resistance of steel component. On one hand, nanoparticles tend to reduce the wear rate of composite by a reduction in the friction (nanoparticles). On the other hand, abrasive Nano polishing is simultaneously induced by hard nanoparticles acting as third bodies, and this would counteract the former effect to a certain extent (nanoparticles). This can explain that the wear rate of steel counter face could decreases with the addition of nanoparticles.

IX. CONCLUSION

As a lubricant, friction-reduction properties of base oil are enhanced by the addition of CuO & Al_2O_3 nanoparticles to a moderate concentration.Dispersing nanoparticles inside base oil, due to the base oil's high viscosity, is a very difficult work. The nanoparticles modified by oleic acid exhibited good dispersibility and stability in base oil.Base oil with CuO & Al_2O_3 nanoparticles increased tribological properties in terms of load carrying capacity, anti-wear and friction reduction than SN-500 base oil without nanoparticles. The results showed that 0.75wt% for CuO nano fluid & 0.5wt% for Al_2O_3 nano fluid concentration was an optimum concentration for wear. The wear in microns of SN-500 base oil without nanoparticles are 10.4 µ, 26.24 µ and 38.86 µ with respect to load conditions 10N, 30N and 50N respectively among all sets of test data.

The anti-wear property at 0.5 wt. % Al_2O_3 concentration of the base oil sample drastically improved the wear reduction at 10N, 30N and 50N loading conditions and the values are 7.39µ, 10.11 µ and 18.72µ respectively. Similarly, anti-wear property at 0.75 wt. % CuO concentration of the base oil sample improved the wear reduction at 10N, 30N and 50N loading conditions and the values are 3.4µ, 10.52 µ and 21.64µ respectively. For the friction reduction test, when CuO nanoparticles were added into base oil, the coefficient of friction reduced by 38%, 44% and 51% at 1wt% concentration as compared to SN-500 base oil without nanoparticles. For the friction reduction test, when Al_2O_3 nanoparticles were added into base oil, the coefficient of friction reduced by 19%, 35% & 52% at 1wt% concentration as compared to SN-500 base oil without nanoparticles. The deposition of nanoparticles on the worn rubbing surface can decrease the shearing stress, and hence reduce friction and wear.

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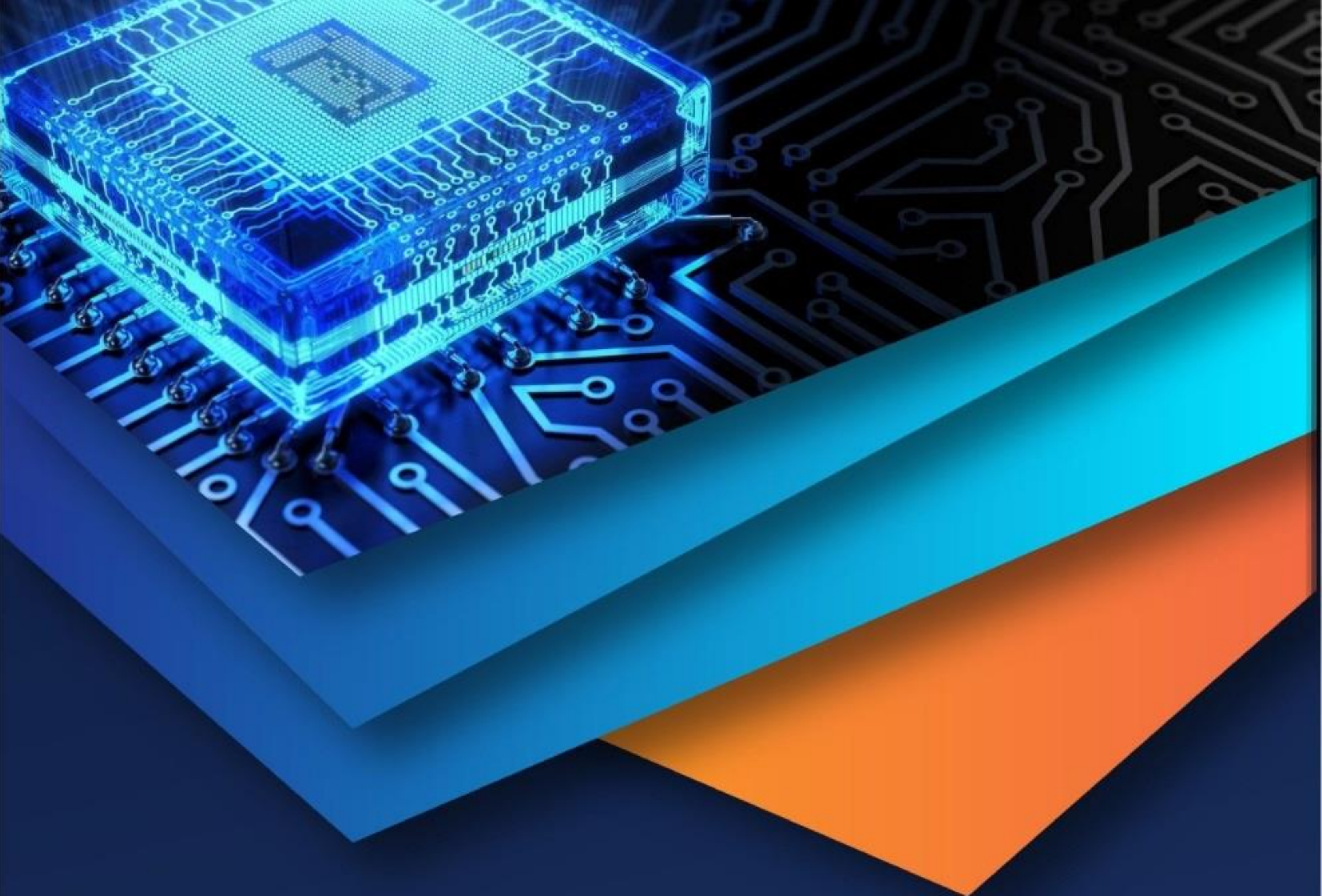

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