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A Review on Investigation of Tribological Behavior of Nanocoating for Piston Ring

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Abstract:- **Nanocoating can help to improve performance and life of automotive engine by reducing the wear between the engine components. In this research have selected the proper material for top piston ring and same material are to be selected for preparation of pin for tribometer testing and material of cylinder liner tested and fabricated the same material of tribometer disc. Nanocoating by electroplated Chromium coating and Chromium nitride using DLC method by PVD coating was done on specimen pin and piston ring and this material which was used tribometer testing.**

Depleting fossil fuel resources, economic competitiveness and environmental concerns has compelled to explore newer avenues to improve efficiency of automotive engines. Various techniques have been adapted to achieve this goal.

Keywords **– Piston ring , cylinder liner, Chromium nitride, PVD**

I. INTRODUCTION

Nanotechnology is based on molecular self assembly new material with dimensions on nanoscale. The size of nanoparticles is mostly in the range of 2-400 nm [1] The material reduced to nanoscale can suddenly shows very different properties compared to what they exhibit on a macro scale and bulk scale.

By allowing the engine to operate at higher temperature with reduced external cooling (heat removal), the fuel efficiency can be improved significantly. There is a need to address several materials related issues such as thermal distortion, high temperature oxidation, creep, etc. Other methods to improve fuel efficiency are to use lightweight material to reduce load, reduce heat losses due to exhaust and conduction through engine body and to reduce frictional losses. Reduction in the weight of engines is a key factor in improving the fuel efficiency. The use of lightweight materials has become more prevalent as car manufacturers strive to reduce vehicle weight in order to improve performance, lower fuel and oil consumption, and to reduce emissions [2].

Most manufacturers have replaced cast iron (density = 7.8 g/cm3) engine blocks with lightweight and low-cost aluminum-silicon (density = 2.79 g/cm3) crankcases. Several Albased alloys and metal-matrix composites, such as A319Al, A356Al, A390Al and A360Al, are in use. However, inadequate wear resistance and low seizure loads have prevented their direct usage in the cylinder bores. The cylinder bores of these aluminum alloy blocks are usually made of cast iron liners because of their good operating characteristics such as wear resistance. These liners need to have a specific wall thickness, which results in a relatively large web width between the individual cylinder-bores, and increases the dimensions and weight of the engine. Moreover, mechanical friction is of another concern that needs to be addressed. Piston system is a major contributor to engine friction. The cylinder bore/piston and piston ring friction constitute nearly all of the piston system’s friction losses [2].

Mechanical Friction is of another concern that needs to be addressed. Piston system is a major contributor to engine friction. The cylinder bore, Piston/Piston ring friction constitute nearly all of the piston system’s friction losses.
However, in case of automotive engine by obviating the need for liners, the engine dimension can be significantly reduced. It is estimated that direct weight savings of about 1 kg per engine can be easily achieved. Also, elimination of liners allows reduction in the overall dimension of engine. Every kilogram reduction of payload is important for improvement in fuel efficiency. Reduction of about 110 kg in a typical automobile of weight 1100 kg will improve fuel economy by 7% [10]. In the lifetime of a car this reduction of engine weight is significant. Application of newer technology and/or materials is being explored to achieve this goal. By employing nanomaterials much of this objective can be achieved. Nanoscale materials have received much attention in recent years due to their outstanding properties compared to those of micron-size counterparts. Nanotechnology to solve the energy problem of the tomorrow’s world

II. LITERATURE REVIEW

Jeong et al. [1] investigated Nanocrystalline materials, as a result of the considerable reduction of grain size and their significant volume fraction of grain boundaries and triple junctions, have exhibited many unusual mechanical, physical, chemical and electrochemical properties compared with conventional polycrystalline or amorphous materials. For many engineering applications, wear resistance is one of the most important mechanical properties because wear accounts for more than 50% loss of all materials in service. They studied the effect of grain size (from 90 µm to 13 nm) in nanocrystalline nickel coatings by electro-deposition on coating hardness and wear resistance, and found that the hardness and wear resistance increase with the decrease of grain size. The yield strength, and toughness of polycrystalline materials are generally improved with decreasing grain size, which is also suitable for nanostructure coatings.

Narendra B. Dahotre, et al. [2] proposed a review of engineering coating for engine applications. Issues relating to dimensional stability, tribological properties on the coating material improve wear resistance, lubrication, coefficient of friction, hot hardness, amenability for coated honing cylinder wall, surface roughness and topography, residual stress, adherence, Coatings for engine and other automotive power systems, Laser induced reaction nanocomposite coating suitable for auto engine applications damage tolerance and resistance, pores density and conditions and cost performance are discussed.

Rajiv Asthana et al.[3], proposed a nanomaterials are an emerging family of novel materials that could be designed for specific properties. These materials will probably bring about significant shifts in the manner we design, develop, and use materials. For example, nanomaterials those are 1000 times stronger than steel, and 10 times lighter than paper, are cited as a possibility. The following properties can presumably be tailored: resistance to deformation and fracture, ductility, stiffness, strength, wear, friction, corrosion resistance, thermal and chemical stability, and electrical properties. [3]

S. Prabhu et al. [4] investigated the CrN coating deposition on the piston ring and piston head, reduction of surface roughness of the reciprocating parts of an internal combustion engine and its frictional loss and thereby improving its overall performance. Improve its wear properties by using physical vapor deposition (PVD) leads to advantages of the hard coatings. The investigation includes the performance analysis of S.I Engine. The power output of the engine is increased by 0.76%.The torque produced by the engine is increased by 0.67%. The surface roughness is reduced by more than 63%.

M. Shunmuga Priyan et al. [5] studied tribological and surface interface characterization of Fe based alloy coating. Powder particles were in the size range of 40 to 80µm which were deposited by HVOF thermal spray under the controlled condition and produce coating layer 400µm. Microstructure and the micro abrasive wear performance of the coating were characterized by Optical microscopic, Video Measuring system and Non contact surface roughness testing analysis methods were used. Evaluation of coating was done by Micro hardness test, Micro abrasion wear test, Surface Roughness test etc. Experimental results indicated that coating provides high surface hardness with excellent wear resistance.

M. Josephson et al. [6] investigated hardness, thermal conductivity and wear rate Wolfram Carbide coating. Developing production process of WC-Co Wolfram – Carbide cobalt alloy coating to decrease the grain size in the material structure to nano domain and minimizing non-WC-Co phases in the material can increase the hardness. Comparison between the microstructure of nano-structured WC-Co coating and the conventional microstructure of WC-Co coating shows that the mechanical properties such as hardness value is double then the conventional micro-grained WC-Co. The improved wear resistance and cutting performance was also observed.

Jeremy (Zheng) Li [7] studied anti-corrosive material performances based on computational simulation, to observe the fundamental anti-corrosive behavior in several different coating materials. The applied model in this computational simulation can be potentially used in future research to analyze different coated material properties and performances. The prototype experiments have been performed to check the coating performances and compare the experiments with computational simulation results. Both computational and experimental methods, with close results, indicate the significant lower corrosive rates in nanocoated materials than traditional coated materials.

Simon C. Tung et al. [8] conducted compressive review of various tribological aspects of a typical power train system including the engine, transmission, driveline, and other components. They investigated integration of lubrication and surface engineering concepts into a unified automotive powertrain system. Industrial Researchers developed lightweight materials such as a non-ferrous material (Al, Mg) for engine and drive train material to replace the current heavy-weight cast iron blocks. The application of tribological principles is essential for reliability of motor vehicle and future trends in nanotrilobology have been shared.

John J. Truhana, Jun Qub, Peter J. Blaub [9] have studied laboratory tests to evaluate piston ring and cylinder liner materials for their friction and wear behavior in realistic engine oils are described to support the development of new standard test methods. A ring segment was tested against a flat specimen of gray cast iron typical of cylinder liners. A wide range of lubricants including Jet A aviation fuel, mineral oil, and a new and engine-aged, fully formulated 15W40 heavy duty oil were used to evaluate the sensitivity of the tests to lubricant condition. Test temperatures ranged from 25 to 100 ^{0}C. A stepped load procedure was used to evaluate friction behavior using a run-in ring segment. At 100 ^{0}C, all lubricants showed boundary lubrication behavior, however, differences among the lubricants could be detected. The extent of wear was measured by weight loss, wear volume and wear depth using a geometric model that takes into account compound curvatures before and after testing. Wear volume by weight loss compared well with profilometry. the friction and wear characteristics of ring and liner materials in heavy duty engines. A wide variety of lubricants ranging from Jet A aviation fuel to fully formulated heavy duty lubrication oil were used to determine the ability of the test methods to detect variations in lubricant performance. Friction behavior was determined by using stepped loading. This approach allows for the determination of lubrication mode as well as the range of friction coefficients.

Petra Obert, Torben Müller [10] have studied reciprocating model test has been developed, which reproduces real load situation of the contact condition between the piston-ring and cylinder liner at fired top dead center(FTDC) of internal combustion engines. Friction, wear, and load carrying capacity (LCC) were studied as a function of temperature, oil supply rate, and normal force for a honed gray cast iron liner and a chromium plated piston ring. The results show similar liner wear to the ones in actual fired engine tests were obtained as long as normal forces that correspond to engine combustion pressures were applied. Also, a considerable dependency of the LCC on temperature and oil supply rate was found. However, oil supply rate did not influence coefficient of friction (COF) as much as expected.

L.A. Dobrzański [11]et al,(2008) presents investigation of the Ti(C, N) and (Ti, Al)N gradient coatings deposited with use of the cathodic arc evaporation CAE-PVD method on sintered tool materials, cemented carbides, cermets and Al2O3 + TiC oxide tool ceramics. The investigation includes the metallographic analysis on the scanning electron microscope (SEM). The surface roughness on the coated material was reduced and the hardness was also increased.

III. EXPERIMENTAL

The substrates for nanocrystalline nickel coatings were AISI 1010 mild steel with a size of 10 x 10 cm^2. They were ground to 600 grit, ultrasonically cleaned in acetone for 5 min. and rinsed using de-ionized water. Nanocrystalline nickel was electroplated onto the substrates by pulse current electrodeposition in a modified Watt's bath containing nickel sulfate, nickel chloride, boric acid and saccharin [1]. The thickness of the nanocrystalline nickel coatings was in the range of 40 ~ 50 µm.

The microstructures of the coatings were characterized by transmission electron microscopy (TEM), Scanning electron microscopy (SEM) and X-ray diffraction (XRD)

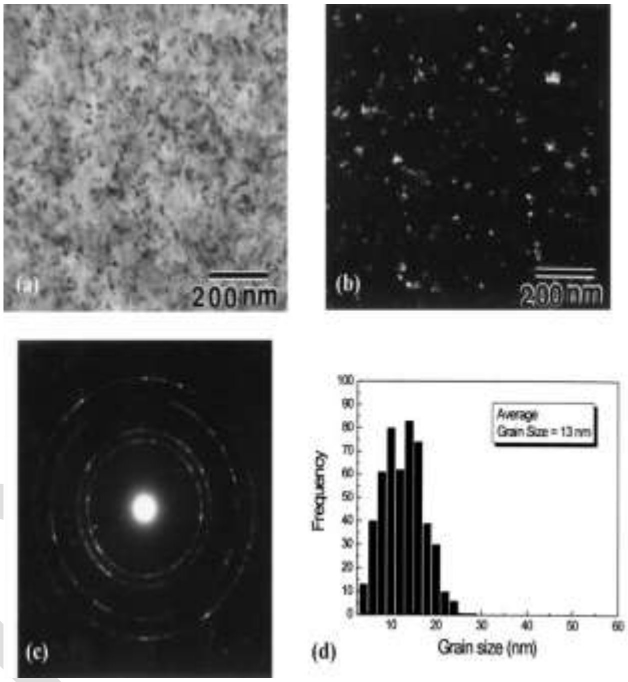

Figure 1. Bright field (a) and dark field (b) TEM micrographs with electron diffraction pattern (c) and grain size distribution (d) of nanocrystalline nickel coating (13 nm average grain size).

They studied 4 different grain size 13nm, 18nm, 62nm, and 214nm. Even though the hardness increases with decreasing grain size from 90 µm to 13 nm, the slope is [1]

IV. DEFECT DENSITY

The defect density in nanoscale materials is very high, but not high enough as in amorphous. As depicted in Fig. 1,

Hall–Petch relation (Hardness for a polycrystal with average grain diameter d, Hd = Hardness of single crystal,H0 + kd$^{-1/2}$) predicts increase of hardness and flow stress

as the grain size decreases. However, as the grain size is very small (in the range of 100 nm), the deformation mechanism changes from dislocation controlled slip to grain boundary sliding increasing plasticity at the same time. When the grain size further reduces almost to become amorphous, the material behaves in visco-elastic manner. This provides a global maximum in properties such as hardness, flow stress, toughness, ductility and thermal insulation (because the conductivity of nanoscale material is much less in certain metallic system such as aluminum due to phonon scattering by high defect density) when the grain size is in nanoscale.

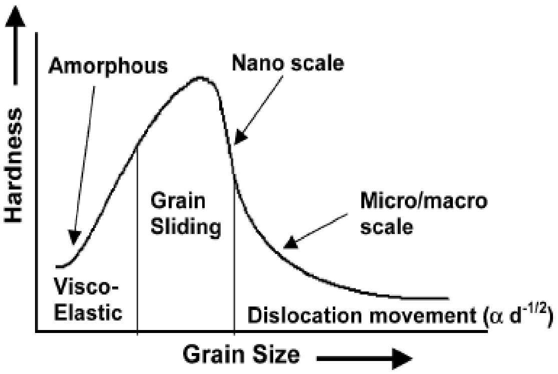

Fig. 2 Schematic depiction of hardness as a function of grain size.

V. COATINGS FOR ENGINE AND OTHER AUTOMOTIVE POWER SYSTEMS

Chromium electroplating is regularly employed to coat the piston rings in engine. Different types of ferrous-based powders, containing C, Si, Sn, Ni, Cr, Mo, Cu, Ti, V and B, etc., are also employed to coat Al alloys for diesel engine applications. APS and Laser Surface Engineering (LSE) have been explored for such coatings. Since diesel engines are exposed to sulfur containing material, corrosion resistance in sulfuric acid is a standard test for such a coating and usually contains aluminide or Mo/Cr in ferrous base coatings Nickel–chromium/chromium carbide coating on piston rings applied through both APS and HVOF techniques have shown potential for improvements on the basis of engine tests. Plasma-sprayed chromium oxide shown to perform better than other coatings in high horsepower diesel engine [2].

Thermal barrier coatings (TBCs) (usually zirconia or alumina–titania) were traditionally applied to gas turbines blades and vanes in order to reduce their operating temperatures and/or increase component durability.

Simon C. Tung and Young Huang [12] have studied the modeling of wear progression of the piston ring cylinder bore system. The aim of this research is to develop an abrasive wear model for the piston ring cylinder bore system during study state operation. There was temperature, load, oil degradation, surface roughness and material properties considered as parameters. There was volume loss Vwear −abrasion due to abrasive wear can be expressed as below which is like to Archard's wear equation.

$$V_{Wear-abrasion} = \frac{XN}{3Pw}$$

By incorporating material hardness data, the model can be theoretical in the piston ring /cylinder bore system. After experiment the conclusion is that, Based on a laboratory simulator, a three body abrasive wear model has been developed to model the wear progression of the piston ring/cylinder bore system during steady state operation

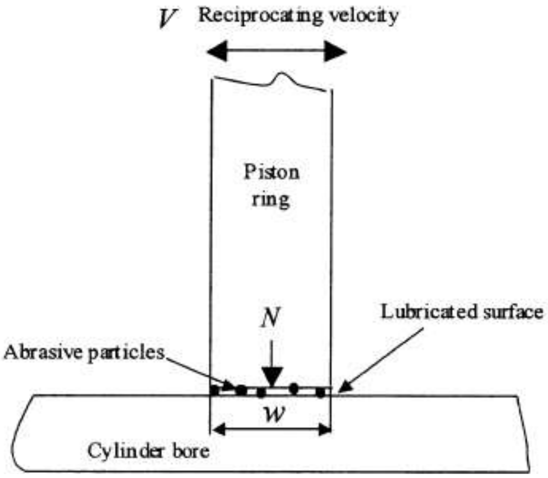

Fig 3.Schematic of the piston ring/cylinder bore simulator system

Om Prakash Sondhiya, [13]Amit Kumar Gupta, Wear Debris Analysis of Automotive Engine Lubricating Oil Using By Ferrography, Ferrography is a technique for analyzing the particles present in fluids that indicate mechanical wear. Ferrography provides Microscopic Examination and Analysis of Debris (particles) found in lubricating oils. These particles consist of metallic and non-metallic matter. The metallic particle is a wear condition that separates different size and shapes of metallic dust from components like all type of bearings, gears or coupling (if lubricated in path). Non-metallic particle consists of dirt, sand or corroded metallic particle. Analytical ferrography is among the most powerful diagnostic tools in oil analysis in tribology. When implemented correctly it provides a tremendous information on machine under operation.

Methodology are used for running the vehicle for 1750km and putting the fresh oil 100ml oil are taken for sample testing for laboratory testing and find out the condition monitoring vehicle.

VI. WEAR DEBRIS ANALYSIS

The primary reason for measuring the quantity of wear debris in used lubricants is usually to determine the wear rates of various components of a machine and in the course of time to measure changes in these parameters. However, an oil sample contains particles which have been produced at various times and it is not obvious how the instantaneous wear rate can be Determined or whether it is necessary to determine the instantaneous wear rate. Various models of lubrication systems (e.g. those of Lotan and of Bendiksen) have been used in the monitoring of aero plane engines using spectrometric oil analysis. Essentially these models take into account the loss of wear particles with oil usage or by the drainage and replacement of oil. These factors are of particular importance because of the high rate of oil use in aircraft and the small particle size; this is the size to which spectrometers are most sensitive. An alternative method is necessary for larger particle sizes and Anderson and Driver have suggested an oil system model for ferrography which takes into account particle loss by filtration and settling. The purpose of this paper is to present an oil system model developed at the National Centre of Tribology primarily for use with ferrography. It is of use in assessing instantaneous wear rates and in the comparison of debris analysis techniques. The basic principle of operation is simple. A representative sample of oil is tested through the following cycle.

1. Obtain an oil sample from a machine.
2. In the laboratory take a measured amount of the fluid and deposit into a clean beaker. The sample is then diluted with a solvent
3. Draw the sample through a membrane filter or use a magnetic separation technique such as the rotary particle depositor to separate the solids from the fluid.
4. The amount of ferrous wear is quantified by means of a debris analyzer such as the PQ2000 manufactured by Swansea Tribology Centre.
5. Visually analyze the debris at 100x magnification under a reflected light microscope quantifying the following parameters: These parameters are then trended in a custom designed software package and the diagnostician awards the unit a Health Status. The health status is a single parameter which gives the unit a level of threat. (Health status is a parameter between 1 -5 with 1 being a healthy machine and 5 being a machine which is imminently threatened with failure.)
6. Repeat the procedure at a decided time interval. Wear debris analysis is a relatively simple procedure not requiring a high skills level to perform.

VII. WEAR MECHANISMS AND PARTICLES

Sliding adhesive wear particles are found in most lubricating oils. They are an indication of normal wear. They are produced in large numbers when one metal surface moves across another. The particles are seen as thin asymmetrical flakes of metals with highly polished surfaces. Cutting abrasive wear produces another particle type. These particles resemble most of all shavings from a metal shop. E.g.: Spiral, loops and threads. These presences of a few of these particles are not significant, but if there are several hundred, it is an indication of serious cutting wear. A sudden dramatic increase in the quantity of cutting particles indicates that the break down is imminent. [13]

VIII. WEAR PROCESS MONITORING TECHNIQUES

The method of wear process can be classified into three main types,

1. Direct detection method:

Wear debris in the lubricant is detected in the machine by arranging for the oil flow through a device, which is sensitive to the presence of debris.

2. Debris collection methods:

Wear debris is collected in a device, fitted to the machine which is convenient to remove, so that the debris can be extracted for examination.

3. Lubricant Sample Analysis:

A sample of lubricant is extracted from the machine and analyzed for wear debris contamination. These methods are normally used to monitor the conditions of components lubricated by a circulatory oil system. When applying a wear debris monitoring method to any machine for the first time there is an initial learning period required, partly to gain experience in using the equipment, but mainly to establish wear debris characteristic levels which indicate normal and incipient failure conditions. This learning period can take up to 2 Yrs. During this time it will also be necessary to establish the inspection and sampling intervals for intermittent monitoring methods such as debris collection and lubricant sampling. This time interval will depend on the application but fortnightly or monthly is probably a reasonable choice for an industrial application in the absence of more precise guidance. Debris collection and lubricant sampling can also indicate the nature of the wear problem and engineers carrying out monitoring need to be given a regular feedback of information on the accuracy of their diagnosis. A scattering of black particle fragments (whiskers) is seen. An unacceptable coating is visible. This indicates abnormal wear. A sample of lubricant is extracted from a machine and analyzed for wear debris contamination. There are two most widely used methods. They are:

1. Spectrometric oil analysis program (SOAP)
2. Ferrography

These methods are normally used to monitor the conditions of components lubricated by a circulating oil system. Two main lubricating sample analysis methods are:

1. Analysis of the sample to determine the concentration of the chemical elements it contains.
2. Analysis of the sample to determine the amount, size and shape of contaminant particles contained in it. [13]

SOAP: It is a maintenance tool which is used to check the condition of the oil lubricated mechanical systems (Examples: Motors, Gear boxes, Hydraulic systems). The systems can be kept under surveillance without dismantling them.

Abnormally worn compounds can be localized and replaced before a catastrophic failure occurs. The quantity and type of wear metals in sample of lubricating oil is determined. The quantity can indicate something about the magnitude of the wear and the type of wear metals can reveal which component is wearing out.

IX. CONCLUSION

From the literature survey found that

The grain size of particle are to be deceases the wear properties of material are improved and used in I C engine the component life also increases.

The ferrous based nanocoating is done to improve wear resistance, lubrication, coefficient of friction, hot hardness, amenability for coated honing cylinder wall, surface roughness and topography.

PVD Coating was improve the performance of engine so efficiency of the engine is increases.

By using the coating to improve the anti-corrosion behaviors of the materials.

To reduce the friction loss between the piston, piston ring and cylinder block.

Wear was measured by weight loss, wear volume and wear depth using a geometric model. It has been ecognize the wear on the piston ring is on the top of the asymmetric crowning when the system is working under boundary lubrication.

Wear debris analysis can improve the condition of engine and preventive maintenance can schedule within time.

After running-in operation the high correlation of the maximum valley depth of the profile with the piston–cylinder assembly wear was noticed. After full load operation a similar strong relationship, but referring to the maximum peak height of the cylinder liner profile occurred. The wear of rings is relatively high. Applying of run-in coating improved reduce the wear loss and reduce the friction.

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