A Technical Review on Tribological Behavior of Multilayer Physical Vapour Deposition Coatings of Piston Ring

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Abstract— Thin film coating is one of the best techniques to reduce the frictional forces and improve the mechanical properties of engine components. The physical vapor deposition (PVD) technology in the recent use to deposit thin film coating on engine components. PVD coating is significantly effective on wear resistance, scuffling resistance, surface roughness, and friction of the components in IC engine. This paper presents studies related to piston ring surface treatment, piston cylinder surface and related theoretical and experimental works. This paper covering many references, aims to shed new light on the surface modification related to the piston ring.

Key words: Piston Ring, PVD Coating

I. INTRODUCTION

The automotive and petroleum industries are deals with government regulations, and latest technology. According to global need higher energy conserving engine fuels and better efficiency vehicles will become increasingly important to saving of natural resources and the reducing of engine components friction. Conventional IC engines are basically made from steel, copper, and aluminum alloys. Since the last decade, light-weight materials such as aluminum-based alloys (A319Al, A356Al, A390Al, A360Al, etc.) are getting popular in IC engine.[1] Weight reduction contributes to reduce fuel consumption by using less energy, as a result, improves the efficiency of the engine. Mechanical friction is another important issue which has major effects on the economy of fuel consumption in IC engine .Higher friction coefficient increases the rate of wear, which affects the life of the engine components.[2] It was reported that frictional loss is responsible for increasing the overall fuel consumption up to 25%. The major frictional loss in IC engine occurs at different places including piston system, cylinder, gear, and bearings. Piston systems are main contributors for friction as 50– 65% frictional losses are occurred in the piston system. The cylinder block and piston ring contributes to the remaining frictional losses. Oil consumption rises due to the existence of poor piston ring sealing and block distortion. Crank, valve system, and bearings also cause frictional losses to a certain level. [7]

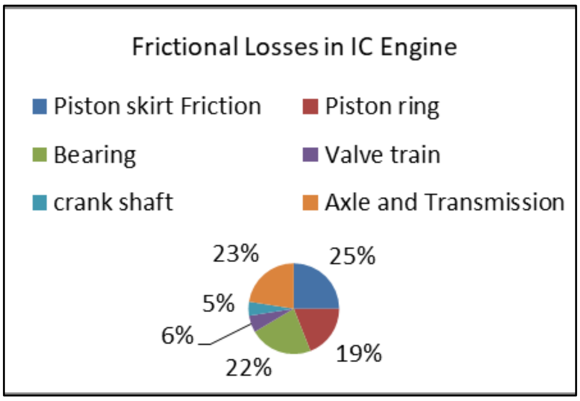

Fig. 1: Frictional Losses in IC Engine [7]

The major challenges in the design of engine are to reduce friction and weight dealing with the high combustion temperature Therefore, it is very crucial to over-come these problems and to improve overall efficiency of the IC engine. Surface engineering provides solution for engine applications. The concept of advanced coating such as multilayer coating has gotten an increasing importance for protection of wear under extreme loads.[3] For example, a potential solution which is currently being applied is the development of thin film coatings on the surface of different components of the engine by PVD process. Development of thin film coating on the components of IC engine improves the hardness, reduces the friction, lowers down the rough-ness, and provides better wear resistance. This study explores the tribological and mechanical properties and the effect of PVD coating on the surface of different IC engine components.[4]

The tribological behavior of piston rings has been an important influence on the performance of internal combustion engines in terms of power loss, fuel consumption, oil consumption and harmful exhaust emissions. The piston ring is the most complicated tribological component in the internal combustion engine to analyze because of large variations of load, speed, temperature and lubricant availability. The primary role of the piston rings is to maintain an effective gas seal between the combustion chamber and the crankcase. The secondary role of the piston ring is to transfer heat from the piston into the cylinder wall. The final function of the piston ring is to limit the amount of oil that is transported from the crankcase to the combustion chamber. [5]

II. EXPERIMENTAL SETUP

A. *Pin on Disc Machine:*

The Pin-On-Disc machine is a unit designed to evaluate the wear and friction characteristics of a variety of materials exposed to sliding contacts in dry or lubricated environments. The sliding friction test occurs between a stationary pin stylus and a rotating disk. Normal load is varied. Electronic sensors monitor wear and the frictional force of friction as a function of load, speed, lubrication, or environmental condition. A pin on disc tribometer is the standard equipment used to determine the sliding friction coefficient and wear resistance of surfaces. The tester consists of a stationary "pin" under an applied load in contact with a rotating disc. Either the pin or the disc can be wear- and friction-tested using the pin on disc tester. The pin is usually a sphere however it may be any geometry that simulates the actual application counter surface. A load cell attached to the pin on disc tester is used to measure the evolution of the friction coefficient with sliding distance.[14] The pin is loaded against the disc through a dead weight loading system. In this experiment, the test is conduct with the following parameters:

1) Load
2) Speed
3) Distance

In the present experiment the parameters such as speed, time and load are kept constant throughout for all the experiment. [8]

III. PHYSICAL VAPOUR DEPOSITION:

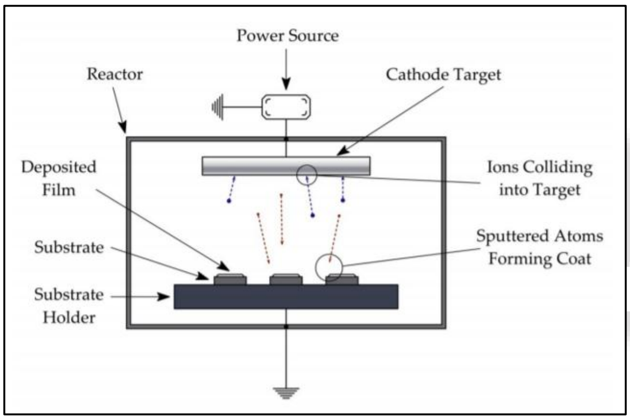

Fig. 2: PVD Method [19]

There are a number of different methods to achieve PVD all of which operate by vaporizing a material, transition of atoms towards a substrate and subsequent deposition of material. One of the oldest and most widely used processes is the method of vacuum evaporation. For this process a current is passed through a target that we want to evaporate and through Joule (resistance) heating the material is vaporized. To produce the vapour a target of the coating material is bombarded with ions. The kinetic energy of these ions is such that when impact occurs coating atoms are ejected from the target and sent towards the substrate. The general operating conditions for PVD are: low operating temperature generally from 200 to 300oC, as the vapour is produced without heating of the target, very low pressure in the reactor, in the range of 0.5-1Pa, deposition speed is in the range of 0.1µm/min. One of the main advantages of this system is the very wide range of materials that can be deposited. Ranging from standard nickel and chrome coatings to deposition alloys, ceramics, oxides and other compounds (e.g. TiN). It is also capable of producing coatings of some polymers. Coatings that are produced are thin, very dense, can have very good surface finishes although this is dependant on the quality of the substrate surface finish.[19]

IV. COATED PISTON RING

The tribological behaviors of piston ring have long been acknowledged as a vital effect on the performance of IC. The variation of young's modulus and hardness of coatings (CrN and Cr2N) on AISI 440C steel with different thickness up to 55 mm by closed field unbalanced magnetron sputtering system. These results further indicated the young's modulus and hardness decrease with gradually increasing of coating thickness for both coatings. The higher hardness of CrN and Cr2N coatings were found 26.2 GPa and 27.3 GPa, respectively. [1] Another factor is that, the increased coating deposition time and temperature may release of compressive stress in the thin film. They observed that hardness of coating increased rapidly from 1.9 to 30 Gpa as compared with uncoated surface. The rapid increase in hardness could be attributed to the formation of dense nano-structure with the addition of Si content. [3] Importance of engine tribology the engine tribologist is required to achieve effective lubrication of all moving engine components. In order to reduce friction and wear, with a minimum adverse impact on the environment. This task is particularly tough given the wide range of operating conditions of speed, load, and temperature in an engine. [7]

Materials	Coatings	Roughness (mm)	Roughness (mm)
AISI 440C steel	Crn Cr2N	26.2 27.3	0.0170 0.016
Cast iron	MoS2 CrN DLC Tin-TiN	6.8 14 30.5 20.4	0.167 0.164 0.165 -
H-13 steel	CrN	18	0.011
Nitrided Steel	CrN DLC	19 14	0.467 0.56

Table 1: Hardness and Roughness properties of PVD coatings piston ring materials. [10-11]

Improvements in the tribological performance of engines can generate the following benefits:

1) Reduced fuel consumption,
2) Increased engine power output,
3) Reduced oil consumption,
4) A reduction in harmful exhaust emissions,
5) Improved durability, reliability and engine life,

V. COATED MATERIAL

A. CR/CRN Multilayer Coating

Cr/CrN multilayer coatings with different number of bilayers were deposited on Ti–6Al–4V alloy substrates by an arc ion plating method. Tension–tension fatigue tests and pin-on-disk wear tests were performed in order to examine the influence of the number of Cr/CrN bilayers on the fatigue and wear properties. The hardness increased with increasing number of Cr/CrN bilayers according to the Hall–Petch equation; however, the magnitude of the increase was minimal. Fatigue strength was improved by the multilayer coatings compared with CrN single layer coatings; in particular multilayer coatings with 3–5 bilayers showed higher fatigue strength. In contrast, in the wear tests, multilayer coatings with 4 or 5 bilayers showed severe wear damage while multilayer coatings with 3 bilayers showed good wear resistance. Thus, multilayer coatings with 3 bilayers were shown to improve both wear and fatigue resistance.[9]

B. TI-TIN Multi-Layer Coating

The improvement of wear resistant properties of a cast iron piston ring-cylinder pair of an automobile internal-combustion engine can exert an important influence on maintaining service properties, extending service life and reducing the repair costs. The internal stresses of coatings using the ion plating technique often causes crack formation and fracture if the mono-layer coating is thicker than 3 µm, whereas, coating on a ring should not be thinner than 4-6 µm in order to ensure enough mileage within one overhaul life of automobile internal-combustion engine. In order to solve the above problem, it was attempted to prepare the Ti-TiN multi-layer compound coating on a cast iron piston ring by a multi-arc and magnetron sputtering ion compound plating technique. A Ti-TiN multi-layer compound coating thicker than 4 mm can be obtained on cast iron piston rings utilizing the multi-arc and magnetron sputtering ion compound plating technique. The coating is 4-5 mm thick and consists of three to nine layers, hardness of multi-layer coating, critical load and wear resistance of multi-layer coating rise with increasing layer-number.[12]

C. Study of Coating Material

Various types of PVD coatings applied to engine components.

Engine Components component	Engine materials	Coating materials	Coating method
Piston ring	AISI 440C Steel, Cast iron, Nitride steel	CrN MoS2 CrN, DLC	PVD
Piston	AISI 304 SS, Al-SI Alloy	DLC TiN	PVD
Piston pin	Aluminum alloy	DLC, CrN	PVD

Table 1: Engine Components and its coating [4-5]

VI. CONCLUSION

We have studied number of research papers and learnt different coating materials (Cr-CrN, TI-TiN) and its properties. The following conclusions can be drawn from the present study. The wear rate of the coatings can be found with the help of pin on disc test under dry sliding conditions. The wear resistance increased with the chromium ion coating on the substrate. The coefficient of friction increases with increasing the load. Different component of IC engine are coated with different coating materials to reduce the wear rate, improve the life of engine, improve the hardness.

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