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Anti-Friction Coatings for I C Engine Piston

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ABSTRACT

In this paper we study different types of coatings on piston skirt and crown area, the focus will be on the anti-frictions coatings and their benefits with respect to fuel consumption, power output as well as wear rate (long durability study).Study will be focused on frictioncoefficient, durability and its effect on piston skirt friction with respect to Molybdenum base mixture, Graphite base mixture, Polytetra fluoroethylene (PTFE) a resin-based antifriction coating, Dimond like coating (DLC).

Keywords: Low friction coatings, Piston skirt, dry lubricant, PTFE, DLC

I. INTRODUCTION

Stricter demands on emission norms, fuel economy and performance require internal combustion engines to be optimized with respect to their frictional losses and wear. While engines ran for the last 100 years without coatings of any type, modern technology has drastically improved the science of piston coatings. While the piston appears to be a relatively simple, stable, solid component on the surface, during operation the piston expands and flexes under combustion temperature and pressure. This movement and stress in the piston absolutely require 100% proper piston prep to avoid delimitating the coating. Many manufacturers have been using piston coatings for decades, but as the benefits of piston coatings have proven themselves throughout the years. Many OEM's have used skirt coatings since the early 2000's because of the undeniable efficacy in modern diesel engines.

Approaches for reducing engine friction include low friction lubricants, reduction of engine friction through design modifications, turbocharged and downsized engines, cylinder deactivation, and hybridization. Transmissions with a higher number of gears also provide the opportunity to reduce engine speed to reduce friction work. Engine friction losses comprise approximately 8 percent of the fuel energy. If friction could be reduced by 25 percent, a 5.6 percent reduction in fuel consumption could be achieved. Advanced low-friction coatings and surface texturing are potentially new methods for reducing friction in reciprocating engines. The design of the piston skirt is one of the key features to be considered in controlling the performance of friction, oil consumption and noise. The piston skirt contributes to around 25 - 47% in piston-cylinder system losses due to engine friction.Along with the characteristics of coatings, which decrease friction coefficient and, consequently, decrease fuel consumption, their ability to avoid increased wear and seizure of friction surfaces under operating conditions is of particular interest.The contribution of the piston assembly to overall engine frictional losses is well documented and has been the subject of a lot of research over several decades.

II. NEED OF ANTI-FRICTION COATINGS

About 7-10% of the total energy input in a vehicle is lost due to mechanical friction, and in an engine, about 50% of the total frictional losses occur at the interface between the cylinder and pistons and piston rings. Therefore, this interface offers great opportunities for friction reduction.In terms of improving the performance of the engine components and forming very demanding, high strength materials, the contact surfaces must show reduced friction, anti-adhesive properties and increased wear resistance.Robust anti-friction coatings become necessary whenever components are continuously subjected to frictional forces. When properly coated, however, the material remains intact and protected for a long time. Lubricity or lubrication's objective is to reduce friction between two mating surfaces to extend the wear life of the components. If the objective is to have a wear in period for the parts to size together then a thicker coating solution is required. If the application is an item with close tolerances or preload factors such as a bearing, then a very thin coating would be best to reduce friction.

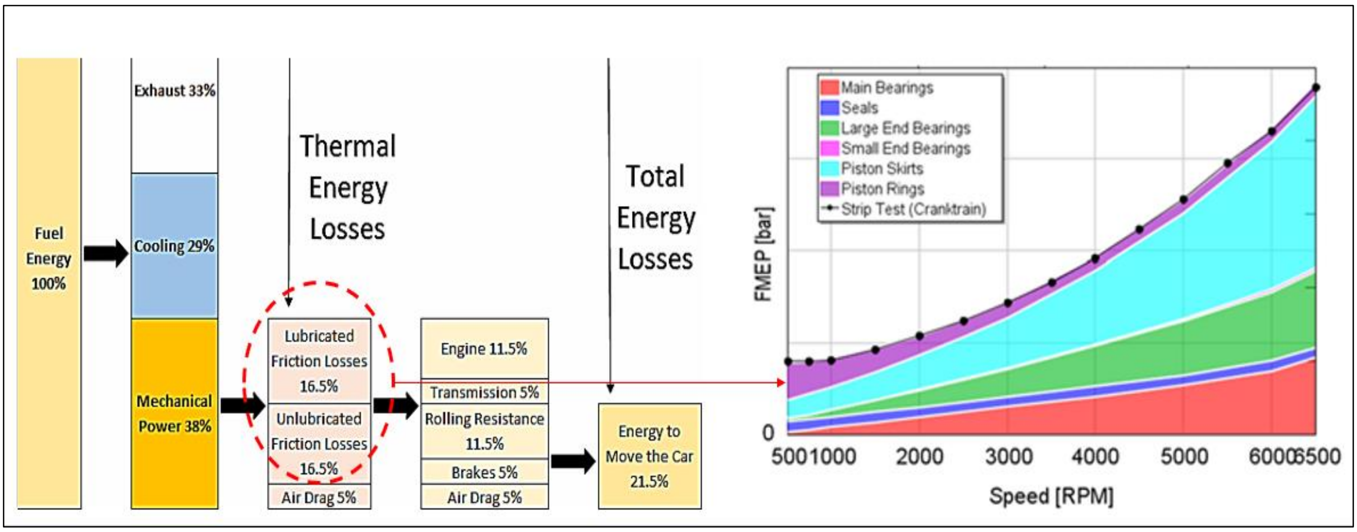


Fig 1. Mechanical losses (Frictional losses) in engine

Low friction coatings provide improved performance and service life while eliminating the need for wet lubricants in operating environments that require resistance to heat, chemicals, or clean room conditions. Coatings enhanced thermal control, improved lubrication, and oil-shedding. Depending on the type of coating and the area in which the coating is applied, the benefits can include increased power, component durability, or both.

III. TYPES OF PISTON COATINGS

Coating the tops of pistons protects and increases the life of the rings on the piston which reduces radial tension loss. Not a lot of people realize this, but the coating helps shield the rings from heat caused by improper burn of the fuel which creates hot spots. Heat kills performance so we want to get rid of it as fast as we can. Coating the tops of pistons helps with scavenging heat out of the motor. The thermal barrier coating on top of the piston helps to push the heat out of the motor. There are basically two types of piston coatings are applied viz thermal barrier coatings to reduce heat loss and anti-friction coatings to reduce the dynamic friction between moving parts

Fig 2.Different types of piston coatings

A. Thermal Barrier Coatings

Also called ceramic coatings, they act as a shield to prevent heat from passing into a part. For instance, a thermal barrier coating on a piston dome prevents combustion heat from being lost beyond the dome. This prevents heat from dissipating through the dome, causing the piston to expand. If there is a barrier coating, combustion heat is greatly reduced, and does not sink into the piston and cause expansion. Since the piston doesn't expand as much you can then run a tighter piston-to-wall clearance. Some of the advantages of thermal barrier coatings are

- High Temperature ceramic-based coatings that can withstand temperatures up to 1,800°
- Coatings that withstand thermal cycling as well as thermal shock
- Performance coatings that are simply unmatched in corrosion and chemical resistance
- A distinct, high-end look and feel
- Cost effective, single coat (straight to substrate), easy to apply products
- Ceramic coating replaces the other coating process like Anodizing, Zinc plating, Nickle plating, Chromate conversions, Powder Coating, Paint

B. Anti-Friction

Anti-Friction-Coatings are touch-dry lubricant solutions which, in their formulation, resemble common industrial varnishes. They contain solid lubricants, resins as bonding agents, as well as solvents. Solid lubricant components are mainly molybdenum desulphated, graphite and PTFE. The individual raw materials and additives, as well as the concentration of solid lubricants are decisive for lubricating efficiency and corrosion protection. Anti-friction coatings also known as solid-film or dry-film lubricants are recommended for applications where extreme operating conditions of very high or low temperatures and significantly high pressures are preventative.Anti-friction coatings provide a low coefficient of friction between two moving surfaces and serve to retain surface oil between moving parts. Anti friction coatings are also able to avoid noises. TheAnti-friction coating's true benefit is reduction of friction, which prolongs part life and reduces operating friction, and it naturally frees available horsepower. A moly skirt coating is not specifically designed to reduce heat, but because it reduces friction, heat is potentially reduced as a direct by-product. Anti-friction skirt coating improves cold-engine startups; the AFC prevents skirt scuffing that might otherwise repeatedly occur in that situation.

C. Dry film or wet film coating

Dry film lubricants are advantageous over wet (oil and grease) when adhesion, lifetime lubrication and appearance, are crucial requirements of the application. Dry lubricants perform exceedingly well at elevated high temperatures extreme pressures and in vacuum. Also, dry film lubricants are environmentally friendlier as there is no after use disposal involved as with wet lubricants. Dry film coatings provide following advantages

- Frees up horsepower normally lost to friction.
- Provides back-up lubrication if the primary lubrication has gone
- Reduces wear which increases engine life
- Reduces heat that can cause galling and seizing
- Produces tighter piston-to-wall clearance
- In majority of applications, lifetime lubrication is feasible
- Hard, durable abrasion resistant finish
- Low Surface Energy
- Dry, clean lubrication unaffected by dust, dirt and moisture
- Controlled film thickness for exact load-bearing capabilities

IV. PISTON COATING PROCESS

Anti-Friction Coatings can be economically applied by hand or drum spraying, dipping, centrifuging (dip-spinning), brushing, roll coating and printing. The size, shape, weight and quantity of the parts being coated are factors in selecting a certain application method. Film-thickness and sliding-surface requirements are other factors. Some of the most used application methods for dry/ solid lubricants are:

- Immersing/ Dipping the Object in Lubricant: This method is common for large batches of fasteners, small ID components and situations where spraying is not possible or desirable. Dip-Spin equipment is often used in these type of applications
- Spraying Technique: This is the most common application method for most dry/solid film lubricants. This is a line-of-sight application method and is only restricted by either small diameter, internal bends, long lengths, etc. Equipment utilized will be dependent on the type of lubricant being applied.

- Burnishing: This method is not very common and typically the least effective regarding bonding. This process utilizes the lubricant, typically in powder form and either a prepared surface or a carrier such as Isopropyl Alcohol, which is then manually rubbed onto the part until a coating is obtained

Anti-Friction-Coatings are preferably applied by immersion or by spraying onto carefully degreased surfaces. Other methods are possible as well, such as immersion centrifuges, electrostatic or automatic spraying methods, application by pressure or roller as well as the various methods for drying and hardening processes which are well-known within industry. The typical steps in applying antifriction coatings are as follow.

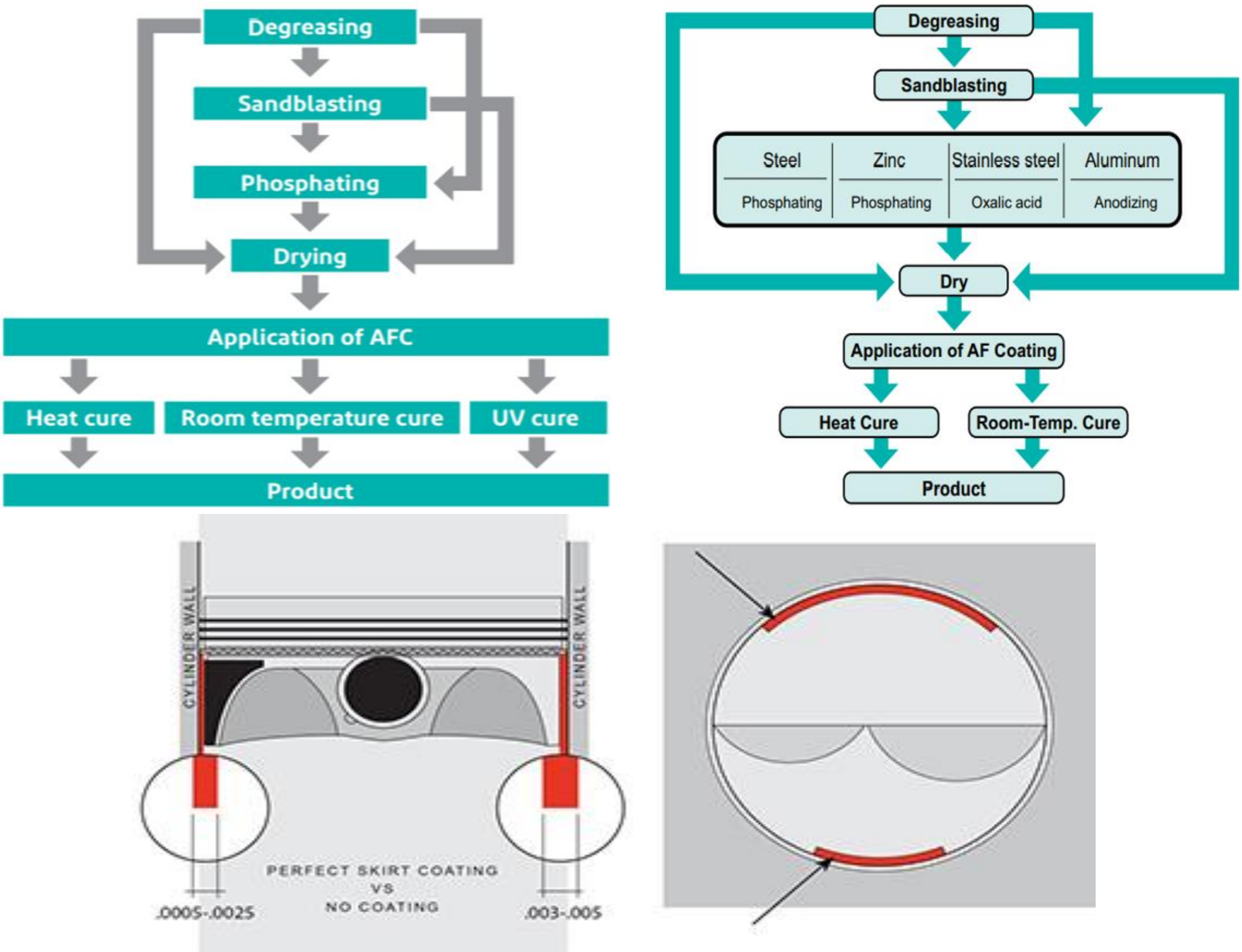


Fig 3: Typical coating process of AF material on piston skirt

Different application methods provide excellent, good or limited results, depending on the anti-friction product. Each method has certain selection parameters, advantages and disadvantages, as shown in the Coating Methods Comparison Chart. Application specialists can help make the right choice based on base material and field of working.

Sr No	Method Selection	Parameters	Advantages	Disadvantages
1	Spraying	• Speed • Quantity of material • Distance • Air pressure • Viscosity of coating	• Good appearance • Even film thickness	• Not so economical • Over-spray waste • Exhaust cabinet needed
2	Dipping	• Long, flat parts • Viscosity of coating • Withdrawal speed	• Good appearance • Even film thickness	• Batch economical • Stirring equipment
3	Dip-Spinning (Centrifuging)	• Form/quantity of parts • Rotational speed • Viscosity of coating	• Good for bulk volume • Economical	• Poor appearance • Two layers • Poor batch control
4	Roll Coating	• Long, flat parts • Viscosity of coating • Withdrawal speed	• Good appearance • Economical • Large surface areas	• Expensive equipment • Large space required
5	Printing	• Mesh size/film thickness • High-viscosity coating • Low-evaporation solvents	• Exact design coverage • Economical	• Special coatings • Viscosity, evaporation

Table 1: Coating Methods Comparison Chart

V. TRIALS WITH DIFFERENT DRY FILM ANTI FRICTION COATINGS

To conclude the benefits of the friction reduction in gasoline engine, following activities has been carried out to compare coefficient of friction for different materials of dry lubricant. Total four solid anti friction lubricants have been tried on the engine piston. i.e., Molybdenum based material, graphite based, Teflon based (PTFE) and Tungsten disulfide. Comparison study of anti-friction dry lubricants is shown in the below table related to the physical properties.

A. Comparison of physical properties of different coatings

Parameter	Molybdenum Disulfide (MoS2)	Tungsten Disulfide (Ws2)	Graphite
Co-efficiency of Friction	0.05	0.03	0.12
Thermal Stability	600 Deg F	1100 Deg F	800 Def F
Load Bearing Capacity	250,000 psi	400,000 Psi	150000 Psi
Temperature Range	-273 Deg C to +650 Deg C	-185 Deg C to +350 Deg C	- 94 Deg F to +700 Deg C
Molecular Weight Density	160.08 5060 Kg.m-3	248 7500 Kg.m-3	12.01 1800 Kg.m3

Remarks	Low friction, fuel and oil resistance, suitable for high temperature use, moderate load carrying capacity, useful for drive shafts, valve trains etc.	Low friction, fuel and oil resistance, suitable for high temperature use, high load carrying capacity, useful for bearings.Coating process is costly	Low friction, fuel and oil resistance, suitable for high temperature use, easy to apply and low cost, renewable and non-hazardous.

Table 2: Physical property comparison of dry anti friction lubricants

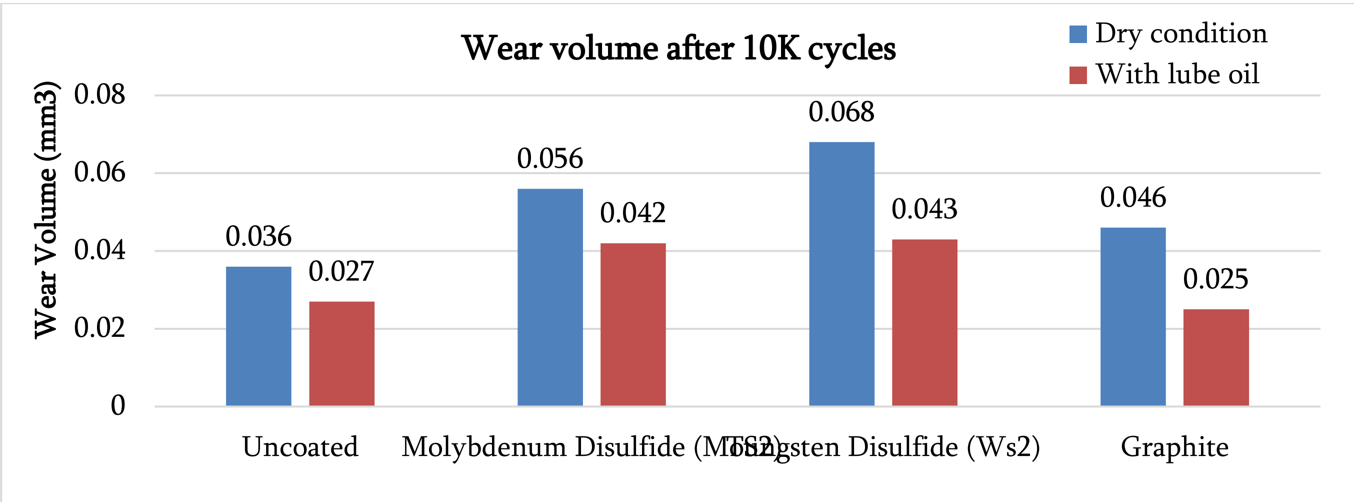
VI. EXPERIMENTAL STUDY

Three different types of coatings have been studied on the gasoline engine piston skirt. The experimental study is carried out with motoring dyno on 1.8 L naturally aspirated BS3 engine with MPFI injection. Engine testing carried out with varying rpm speed and load (automotive application) as well as constant speed with varying load (Generator application). Following graphs are plotted to understand the behavior of the engine under various conditions.

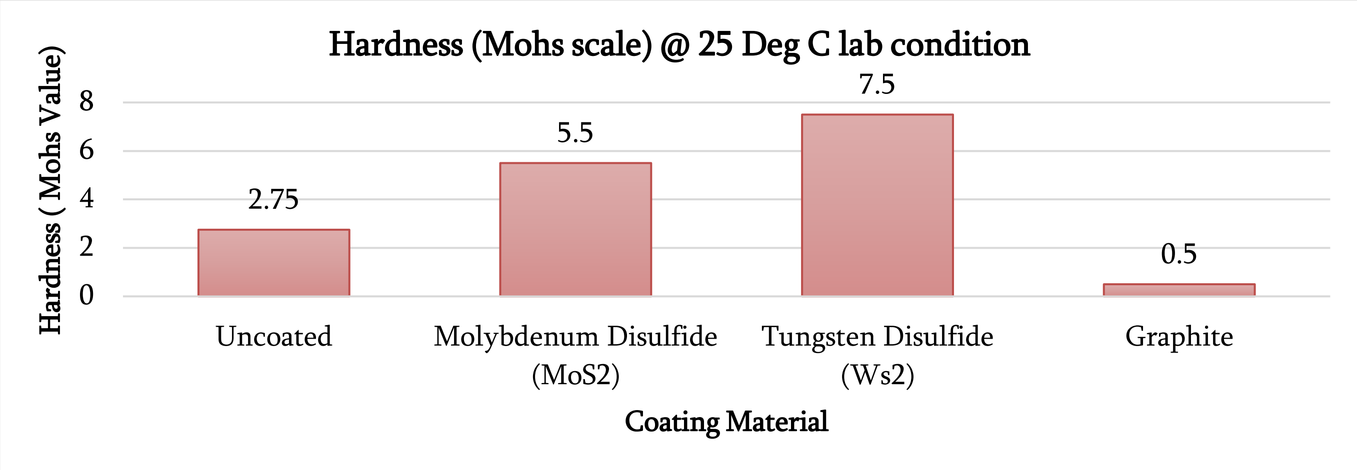
- Wear rate of different coatings over 10,000 cycles of operation under dry condition
- Hardness variation with respect to operating temperature
- Friction power comparison in four strokes of an engine

VII. FRICTION COATING WEAR STUDY

Wear resistance refers to a material's ability to resist material loss by some mechanical action. Wear volume of the material is directly related to hardness and coating thickness. Higher the thickness of coating, more is the wear rate due to low clearance in between parts. Hardness also plays vital role because harder material wears at lower rate, but the coefficient of friction will be higher due to the low micro scoping pores to retain the lubricating oils. Another important factor is about the presence of lubrication oil during operation, as a fact the softer material performs better with respect to friction during operation in the presenceof lubricating media.

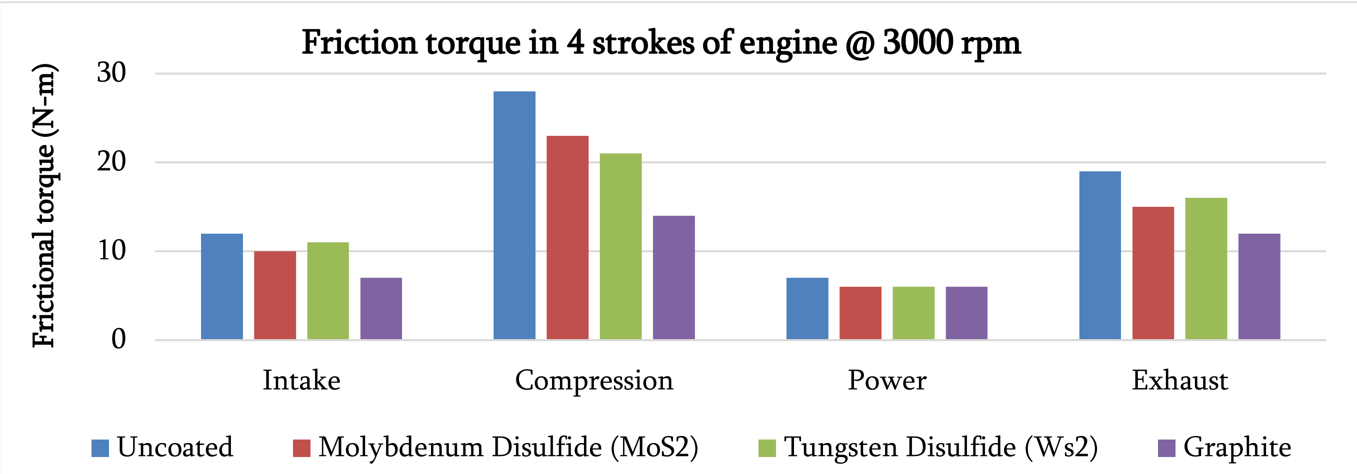


The following figure shows the details of harness measured in Mohs value. The Mohs scale is the hardness of a material is measured against the scale by finding the hardest material that the given material can scratch, or the softest material that can scratch the given material.The Mohs scale is a purely ordinal scale, and it ranges from 1 (For talc) to 1500 (for Dimond). Even though harness is directly related to the wear rate, but the friction coefficient reduction is also of equal importance in this study. Low hardness material with micropores for retention of lube oil is the focus in this study to reduce the engine friction.



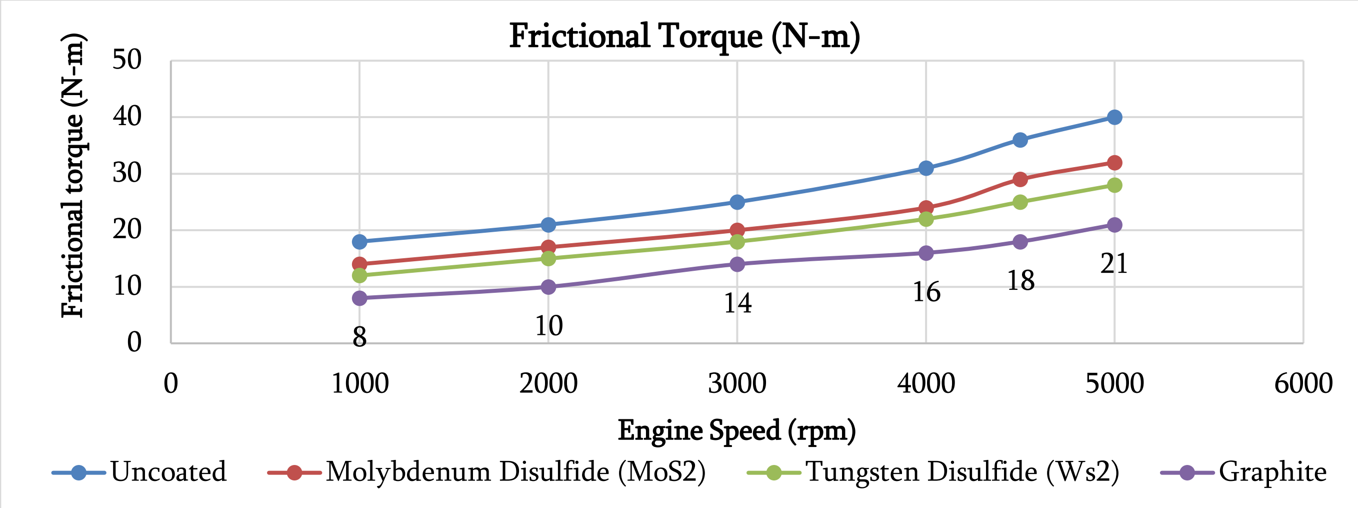
A. Frictional power in different strokes of an engine

As we are aware the friction will be higher on the engine during the compression stroke because of the rubbing of parts when there is a load against the piston. This friction is not only because of the piston skirt but the presence of smooth gliders with oil retain makes piston move faster and extract useful energy by reducing friction between liner and piston skirt.



B. Frictional torque of an engine

Present research work is focused on the investigation of friction power as a function of engine speed, load, and oil viscosity, and engine components operating predominantly in hydrodynamic regime (piston ring assembly and bearings) are considered as major contributors towards engine friction power loss.Engine load also plays a vital role in engine friction to eliminate this effect we have used motored dyno to measure the torque based on the rpm factor. As a basic principle the frictional power will be higher in case increased rpm. To analyze the effect of friction with different coatings experiments has done and results are plotted with graph as shown below



VIII. RESULTS AND DISCUSSION

The coatings have been experimentally studied without lubricating material in order to study friction and scoring resistance of the coating materials, which are employed in a piston skirt of high-force diesel, which is usually exposed to short-term boundary and even dry friction. This study has demonstrated that the friction coefficient of the specimens with a solid lubricating coating is lower, and the seizure load is higher than those of the specimens without a coating. A five-fold decrease in friction losses and an increase in the service life of piston skirt of high-forced petrol can be achieved in the coatings.A brief analysis indicates that possible benefits should be closer to 3% at high engine loads.To establish coating effectiveness, carefully controlled fuel economy testing of engines was performed on aEddy current dynamometer at one engine speed and two output torque levels (50% load & 100% load) and also on different rpm load.

- Friction power reduction using graphite coatings shows positive results in conjunction with liquidlubrication. Graphitebeing soft material has more anti friction property even though it has low hardness and high wear volume percentage.
- With higher speeds the friction power reduction in engine due to application of graphite is nearly 45% under motoring condition.

IX. FUTURE WORK

To improve the wear rate as well as long duration operation, antifriction coatings with different additives like molybdenum and tungsten can be applied with low-cost production. The combination of coatings benefits in case liners are also coated with antifriction with better oil retention capacity on the surface. Wear capacity improvement on the graphite with different additives or combination with molybdenum or tungsten will provide an added advantage.

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