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# Effect of liner surface properties on wear and friction in a non-firing engine simulator

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**Abstract**

The performance of a combustion engine is closely related to the friction force and wear between cylinder liner and piston rings. It is believed that this friction force can be significantly reduced by optimizing the surface topography of cylinder liners. Therefore, it is necessary to understand how liner surface topography affects wear, friction and lubricating oil consumption. Several experimental studies have been carried out for evaluating wear and friction in simulated engine conditions using Cameron–Plint wear testers, Pin-on-disk testers, SRV testers, etc. However, these studies do not reflect the true behaviour of inside the engine because of stroke length limitations. In this paper, a non-firing engine simulator has been developed in order to simulate engine conditions to a closer extent compared to these machines. This simulator can operate at similar linear speed, stroke, and load as real engine and can simulate almost all engine operating conditions, except firing pressures. In the present study, a production grade cylinder liner has been used for the experiments conducted using a custom-made non-firing engine simulator. The wear and surface property behaviour were evaluated at several locations in the liner and found that after running-in an engine, surface of cylinder liner exhibits plateau-honed-like characteristic. Energy dispersive analysis (EDS) has been carried out of liner and top ring for evaluating materials transfer. Coefficient of friction between three different liner segments and ring was evaluated using an SRV wear tester. Coefficient of friction in the piston ring–liner interface increases with increasing average surface roughness for liner.


*Keywords:* Reciprocating wear tester; Liner; Plateau honing; Surface profile; Scanning electron microscopy

## 1. Introduction

To meet competitive durability goals in the automobile industry, it is necessary to have improved understanding of the effect of wear in the cylinder liner piston assembly. Cylinder liners require some of the most critical surface properties in terms of functionality. Piston ring and cylinder liner wear is a very important factor in determining effective engine life. A polished liner will not be able to retain oil and will have poor tolerance for wear debris. Poor lubrication gives rise to metal-to-metal contact between cylinder liner and piston rings, and can lead to exceptionally higher wear and scuffing. Rough liners have very high coefficient of friction and high rates of wear in spite of their good oil retention capacity. Hence a balance between the two is required in order to achieve lower friction, wear and longer engine life.

The power cylinder is a major contributor to the overall mechanical friction of the engine. Mechanical power loss amounts to approximately 10–15% of the total fuel energy. Approximately half of this mechanical loss is because of friction at the cylinder liner–piston ring interface [1,2]. The Piston ring assembly plays a very important role, providing a dynamic seal between combustion chamber and crankcase. This seal minimises the expansion stage power loss due to pressure loss from the combustion chamber to the crankcase. Wear between the piston rings and cylinder

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liner has to be minimised in order to ensure lower power loss from assembly over longer duration.

The components that are exposed to continuous friction are compression rings, oil control rings, piston skirt and piston pin. Oil rings, due to their substantially higher ring tension, operate under boundary-lubricated condition. They contribute as much as twice the friction of each compression ring [3,4]. Wear near the top dead centre is often a limiting factor to the life span of an engine. Major design factors, which influence piston assembly friction are; ring width, ring face profile, ring tension, ring gap, liner temperature, skirt geometry and skirt bore clearance [5].

The study of the tribological properties of the cylinder liner and piston ring system in an internal combustion engine has attracted much attention in the last few years. Cylinder-liner wear is known to play a major role in internal combustion engine durability, performance, emissions, fuel economy and lube oil consumption.

The cylinder walls are stressed mechanically by high gas pressure and side thrust of the piston, as well as thermally due the high gas temperatures. Since all these stress-induced factors are cyclic in nature, the cylinder liner materials must have good mechanical and fatigue strength, otherwise cylinder bore distortion or early material fatigue failure may take place. Liner assembly stresses are also very high. These stresses are even higher than the firing stresses and the stress due to piston slap.

In addition, the tribological properties such as wear and scuff resistance must also be satisfactory because metal-to-metal contact between the piston rings and the cylinder liner do occur. However, all these desirable properties cannot be found in a single material. "Trade-off" between the mechanical and tribological properties must be considered during the selection of the appropriate liner material based on the application requirements. Grey cast iron is widely used as liner material for heavy-duty diesel engines. Three methods of improving the wear resistance of grey cast iron liner are: (a) adding special alloy elements, (b) using a surface treatment technique such as induction hardening, gas nitriding and (c) applying surface coatings [6]. Induction hardened liner and special alloy grey cast-iron liners offer better wear resistance with new and used oil as compared to grey cast iron liners.

### 1.1. Liner surface preparation

The preparation of the surface of cylinder bore is a multi-stage process. Surfaces are typically machined in two steps. First, a rough honing gives the right cylindericity, and engraves deep valleys on the surface (up to 10 μm deep). Second, a finish-honing step, also called plateau honing, gives a relatively smooth surface to the plateaux [7]. The cylinder bore honing quality is an essential factor for a good engine performance and durability. A bad surface finish may lead to excessive lubricating oil consumption, high piston ring wear and scuffing. Honing angle, which is determined by the vertical and rotational movement of honing head, is directly related to oil consumption. Lubricating oil consumption decreases with increasing honing angle as shown in Table 1 [8].

After running in an engine for a relatively short time, a normally honed liner will exhibit a surface profile similar to a plateau-honed liner. However, the large number of wear debris generated during the running-in period may damage the engine severely as they act as abrasive particles which get embedded in the liner surface. Plateau-honed surface is relatively stable in terms of wear. Therefore, initial wear can be controlled by building plateau-honed surface of the liner during the manufacturing process and thereby relieving the engine of the burden of large initial wear and associated debris. During the later part of life of the liner, the plateau surface would continue to posses relatively large, smooth plateau, which provide a large bearing area, and also deep valleys to retain oil for lubrication between the surfaces and provide a relief area for wear particles. Tim and Mike [9] examined the effect of plateau honing on both rough and smooth liners and found that smooth plateau liner ($R_a \approx 0.78$ μm) offers better finish with regard to oil consumption, ring wear, liner wear between the ring turnarounds and volume of liner material lost due to wear.

Wear of liner is different at thrust side than anti-thrust side and also it varies over the stroke length. This can be seen in an exaggerated view of liner shown in Fig. 1. Higher

Table 1
Effect of honing angle on oil consumption [9]

| Honing angle (°) | Oil consumption (g/kWh) |
|---|---|
| 23 | 0.58 |
| 70 | 0.59 |
| 120 | 0.37 |

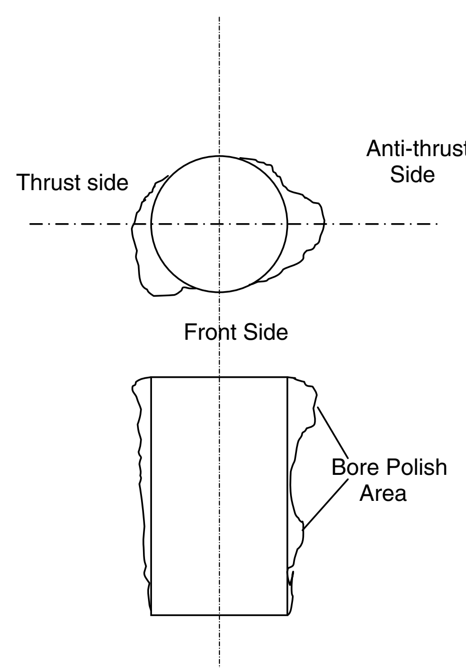


Fig. 1. Exaggerated diagram of typical cylinder liner wear [14].