Techniques used to improve the tribological performance of the piston ring-cylinder liner contact

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Abstract. The mechanical assemblies in automotive engines are usually lubricated by a combination of oil and solid lubrication films. Consequently, the significant current challenges for developing the tribological behavior of vehicle engines need the lubricants that conform to different operating conditions by providing mechanisms for reducing friction and wear. This article summarily reviews the techniques used to improve the tribological performance for piston ring-cylinder liner contact and evaluates their effectiveness to provide the most assuring approaches to reduce friction and wear. The objective was to explore the areas where there are openings for further research contributions to achieving an improvement in the piston ring-cylinder contact in automotive engines.

1. Introduction

The principal source of energy is fossil fuel. The problem of wasted energy is the main factor the world seeks to reduce it and get the best performance with the lowest cost. Vehicles are one of the most important applications that use fossil fuel and represent 30% of energy consumption in order to overcome the resistance and move the vehicle [1, 2]. The consumption of energy ratio is distributed as shown in Fig.1. The engine takes the most likely percentage of 70% of the total power losses, recent literature suggests that the total friction due to the piston rings contributes for 40–55% in a modern spark-ignited (SI) or diesel engine, while the engine friction represents 8% of the wasted energy, but it is overcome this ratio and improved it will be positively affecting the large level of fuel saving and the money accordingly. Figure 2 showed that the distribution of power losses in the engine [3, 4].
This paper aims to illustrate the strategies of improvement the tribological performance of piston assembly to reduce the frictional power losses and save the fuel. Consequently, there are more than one approach that has been followed to achieve the appropriate tribological performance. Three major methods have been used to reduce friction and wear of the frictional surfaces in engines as follows.

2. Nano-lubricants technique

One of the techniques can use certain nano-additives (nanoparticles) in the lubricant to produce the boundary tribofilm via chemical and physical mechanisms. Of late, the researchers interested in improving characteristics of lubricants have been using nanoscale-based materials as nano-additives which could be added in both liquid and solid lubricants [5-14]. Therefore, the choice of nanoparticles is a significant step to develop the tribological performance. Dai et al. [7] explained the distribution of proportions of the nano-additives in the lube oils as shown in Fig. 3a where the largest proportion was for the metal and metal oxides. Moreover, the most common additives are the spherical morphology then follow it the sheet and nanotube respectively as shown in Fig. 3b. The spherical nanoparticles have shown superior tribological performance more than carbon nanotubes. The reason is strongly related to the rolling mechanisms between the worn surfaces during the sliding process [15]. In the subsequent section, the mechanisms of the friction and wear reductions using various nanomaterials as nano-lubricant additives have been discussed.

Ali et al. [16, 17] studied the how to bring down frictional power losses and improving the anti-wear properties in vehicle engines using Al₂O₃/TiO₂ nano-lubricant additives with a concentration of 0.1 wt.%. According to the results obtained, there was a decrease of the frictional power losses for the ring/liner assembly by 40-51% compared with the base oil (5W-30). This is due to the boundary tribo-
film as shown in Fig. 4. Furthermore, it can be observed that the surfaces morphology which used the base oil showed a micro-exfoliation and scuffing, indicating that severe adhesive wear had occurred as illustrate in Fig. 5. This is due to the penetration of solid inclusions in the soft surface materials by tillage, which eventually resulted in abrasive wear, confirming the results of the high friction coefficient.

Pisal and Chavan [9] studied the effect of the 0.5 wt.% CuO nano-additives on the tribological performance. The results exhibited that the anti-friction and anti-wear improved by percentages 24% and 53%, respectively, as compared to commercial engine oil. Another results also by Peña-Parás, et al. [18] demonstrated that the wear scar diameter decreased by 86% at 0.01 wt.% concentration. Moreover, the experimental results by Wu, et al. [14] revealed that CuO nanoparticles were added into two type oils. The results presented that the friction coefficients were reduced by 5.8 and 18.4%, respectively compared to the base oils.

3. Coating technique
Current progress in surface manufacturing and coating technologies provided novel possibilities for best-controlling in friction and wear, especially under boundary lubrication regime contact conditions [3]. Highly adherent coatings of very high quality can now be deposited by a variety of techniques at thicknesses from <1 to >100 nm. Figure 6 shows some ways of manufacturing the surfaces by the coating. The coatings can be adapted with the engine systems to be operated with lower viscosity oils and reducing the harmful additives. Applying some type of coatings can be reacted with oil additives.
in the engine to produce an excellent chemical tribo-film; the other type may provide supreme hardness and hence high resistance to wear and scuffing. Using the technologies of the nano-composite coatings will be providing a longer life of the engines. These coatings can also contribute excellent protection against corrosive and oxidation under severe conditions [19]. Doped MoS$_2$, e.g., MoS$_2$/Sb$_2$O$_3$/Au, low friction coatings are used in satellite components, shafts, gears, and bushings. UNCD coatings are used in mechanical shaft seals in rotary equipment, such as pumps and mixers. Pure and Si doped DLC coatings are also being studied for potential use in the automotive industry (camshafts, valve tappets and piston pins/rings) and the biomedical industry [20].

Anti-friction/wear coatings are used when rubbing parts are loaded with a high load, the abrasive material is present, or corrosion is probable to occur, or levitated temperatures can be expected. The surface of the rubbing element is then protected by a special metallic or inorganic non-metallic hard coating to reduce wear [19]. The surface layer of the material may also be modified by ion implantation or laser treatment. High wear resistance of DLC-coated was applied directly to aluminium engine walls and piston as shown in Fig. 7 to develop the performance of the engine. The results exhibited that there is still a high potential to reduce friction, where, the weight of the piston reduced by 5%, friction reduced by 20%, heat transfer improved (higher output) and fuel economy improved by 2-3%. The engine has volume space 125 CC, 4-cycle, air-cooled, max speed is 13000 rpm. From the result of tests obtained from coated and uncoated pistons. The utility power was improved owing to used A.DYLYN coating as shown in Fig. 8 [22].
Figure 8. Increase in brake power due to piston coating by A.DYLYN applied normally only for racing applications [22].

4. Solid-lubricants technique

Solid lubricants are required and used for aerospace and automotive mechanical applications in different forms, as burnished films, mixed with the main matrix for providing self-lubricating, as an additive to traditional lubricants such as grease as very thin films deposited by vapour deposition techniques [23]. Anti-friction/wear solid lubricants are applied when oils or greases were cannot meet the requirements of some working environments like high temperature, an oxygen/nitrogen surrounding, vacuum, radioactivity, etc [24].

Tribofilm is described as a solid film produced as a consequence of the sliding process, which is adhered on its frictional surface but has a complex structure, chemical composition and tribological behavior. Up to date, the fundamental understanding of self-lubricating is increasingly enriched, particularly attributed to the instrumental advances in materials characterization techniques [25]. Self-lubricating is an effective way to resolve many very difficult problems of lubrication in miniature systems. Essa et al. [26, 27] studied the effects of ZnO and MoS$_2$ as a solid lubricant with concentration on the tribological properties of M50-steel (M) under conditions 25 to 800 °C temperature, 12 N load and constant sliding speed of 0.2 m s$^{-1}$, the tests were conducted by using a pin-on-disk test pinch. According to the results, it is clear that the anti-friction properties of the M50-steel have been improved by using solid lubricants.

5. Conclusions

Based on all the literatures, the majority of nano-lubricants consisted of metal oxides, metals and sulfides. The majority of nanoparticles morphologies are spherical, followed by granular sheet, onion and nanotube. Other studies reported that the coating technique could not achieve self-replenishment of the tribofilm formation with a shorter coating lifespan. However, the self-lubricating by solid lubricant is necessary to maintain the lifespan of the mechanical parts, especially in the boundary lubrication regime. Finally, the mini-survey acts as a guiding path of the techniques used to improve the tribological performance of the piston ring-cylinder liner contact.

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