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Evaluating the Performance of a Diesel Engine Using Aluminum Nanocoating Based Piston Rings

Karikalan Loganathan*, Ramasubramanian Shanmugam, Lalith Kumar Arulanandharaj, Ashok Selvam, Jothi Venkat Jaganathan and Sugan Jeyals Arokiaraj

Department of Automobile Engineering, Vels Institute of Science, Technology and Advanced Studies, Chennai, Tamil Nadu, India

***Correspondence to:**
Karikalan Loganathan
Department of Automobile Engineering,
Vels Institute of Science, Technology and Advanced Studies,
Chennai, Tamil Nadu, India.
E-mail: karilk1972@gmail.com

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Abstract

Numerous studies have demonstrated that the phenomenon of frictional loss within an internal combustion (IC) engine holds paramount significance in the determination of both fuel efficiency and overall performance characteristics exhibited by a given vehicle. The experimental evaluation of the transient friction and running-in behavior characteristics of aluminum nanoparticles-based piston ring is conducted utilizing a specially designed engine testing device. The findings are presented for an order of experiments conducted on rings using various combinations of disparate materials. This study presents a comparative analysis of three distinct materials utilized in the manufacturing of piston rings. The utilization of a hemispherical piston in conjunction with aluminum nanoparticles-based piston ring exhibits superior performance compared to alternative combinations.

Keywords

Nano coated, Engine, Piston rings, Torque, Power, Smoke

Introduction

Manufacturers of diesel engines are consistently confronted with the challenging endeavor of identifying avenues to lessen fuel consumption and minimize pollutants, with the ultimate goal of enhancing engine efficiency. The significance of frictional loss in an IC engine has been demonstrated by researchers, as it plays a crucial role in determining both the performance characteristics and fuel efficiency of the engine. In order to enhance performance, researchers have conducted numerous investigative studies on the piston ring. In a study conducted by researchers, the fuel economy and emissions of engines were examined by comparing the performance of engines equipped with partially textured and non-textured barrel shape piston rings. The findings of the study indicated a notable 4% decrease in fuel consumption [1, 2]. One approach to enhancing the performance of piston rings is to leverage the latest advancements in nanocoating technology. The process of surface coating involves the application of a thin layer of a suitable substance onto the surface of the piston ring in order to enhance its frictional properties and resistance to wear. Previous scholarly research has also encompassed investigations into various nanocoating materials utilized in the context of piston ring applications [3-5]. Typically, these features lead to a reduced friction in comparison to the metallic layer/hard coatings [6-8]. Extensive research has been conducted on nanocoating's intended for use on rings, yielding encouraging findings as stated in references [9-12]. Coatings have demonstrated the capacity to enhance the thermal efficiency of pistons by effectively reducing friction. For instance, it was demonstrated that the implementation of a ceramic coating might result in a 48% enhancement in the heat conductivity of pistons in certain scenarios [12-15].

Piston

The conversion of thermal energy from fuel into mechanical energy is facilitated by the piston in an IC engine. Pistons are exposed to significant mechanical and thermal stresses. The piston experiences mechanical stresses due to the intense pressure cycles in the combustion chamber, where peak pressures can reach up to 200 bar. Additionally, the piston is subjected to significant inertia forces resulting from the extraordinarily rapid acceleration it undergoes during its reciprocating motion. The thermal stresses experienced by the piston are a consequence of the combustion process, wherein the combustion chamber reaches peak gas temperatures ranging from 1800 to 2600 °C. In the context of pistons, these issues manifest as the need for optimal strength characteristics within the appropriate temperature spectrum, while simultaneously minimizing weight.

The piston serves primarily in the following ways: One primary goal is for the connecting rod to transfer the force of the gas to the crankshaft. To work in tandem with the piston rings and the combustion chamber to prevent oil from the crankcase from entering the combustion chamber and to stop gas from escaping to the crankcase. Third, transfer the heat of combustion to the cylinder lining and oil for cooling.

Piston rings

Piston ring wear occurs as a result of their movement within the cylinder bore, which is influenced by both their gas load and the inherent load exerted on the ring. In order to mitigate this issue, the components are constructed using wear resistant material, such as steel and cast iron, and are subjected to coatings or treatments that augment their resistance to wear [16]. The design of ports in two-stroke engines is also crucial for the longevity of the rings. In contemporary motorcycle engines, a range of exclusive configurations are employed to optimize the durability of piston rings. Illustrative instances encompass distinct port configurations such as tapered serrations, alongside the utilization of diverse combinations of heat treatment and specialty coatings administered by physical vapor deposition methodologies and other related approaches. In general, it is customary for the upper ring and oil control rings to undergo a surface treatment such as chromium coating, nitride coating, plasma spraying, or physical vapor deposition ceramic coating. In order to boost scuff resistance and optimize wear performance, a majority of contemporary diesel engines are equipped with top rings that are covered with a modified chromium coating referred to as CKS or GDC. These coatings, developed and patented by Goetz, incorporate aluminum oxide or diamond particles within the chrome surface.

The piston rings job in engines are: (i) Sealing the combustion space so that as few gases as possible leak into the crank case, (ii) Making it easier for heat to move from the piston to the wall of the cylinder, (iii) Keeping the right amount of oil between the piston and the wall of the cylinder, and (iv) Controlling how much engine oil is used by moving oil off the walls of the cylinders and back into the sump.

Methodology

The primary objective is to enhance the operational efficiency of a diesel engine by the utilization of a combined piston and piston ring system, hence optimizing engine performance. The first configuration under consideration is a hemispherical piston (Figure 1) equipped with aluminum-zirconium (Figure 2) rings. The second configuration involves a hemispherical piston with cast aluminum rings (Figure 3). Lastly, the third configuration entails a hemispherical piston with aluminum-titanium rings (Figure 4). In order to optimize the performance of a diesel engine, it is imperative to discover the combination that will yield superior results.

Experimental investigation

The investigation was conducted utilizing a water cooled DI diesel engine, featuring four cylinders. Different types of nano-based piston rings were fitted in the engine to assess its performance. The piston, in its diverse forms, can be paired



Figure 1: Hemispherical piston.



Figure 2: Aluminum-zirconium rings.



Figure 3: Cast aluminum rings.



Figure 4: Aluminum-titanium rings.

with different types of rings. These configurations include the hemispherical piston with alumina-zirconia rings, the hemispherical piston with cast aluminum rings, and the hemispherical piston with alumina-titanium rings. The measurements comprised a wide range of engine performance and pollutant properties, such as torque and power output. Fuel consumption and smoke emissions. Table 1 shows the engine specifications.

Results and Discussion

Figure 5 presents an assessment of torque for the combination of a hemispherical piston with aluminum-titanium, aluminum-zirconium and cast aluminum rings at a crank angle of 18 degrees. The torque of cast aluminum rings with

Table 1: Engine specifications.

Engine power @ 2200 rpm	80 HP
Torque @ 1400 engine rpm	280 NM
Power @ rated engine speed	75 HP
Type	Diesel
Number of cylinders	4
Injection	Direct
Bore	101
Stroke	127
Cooling	Water
Compression ratio	15.3:1

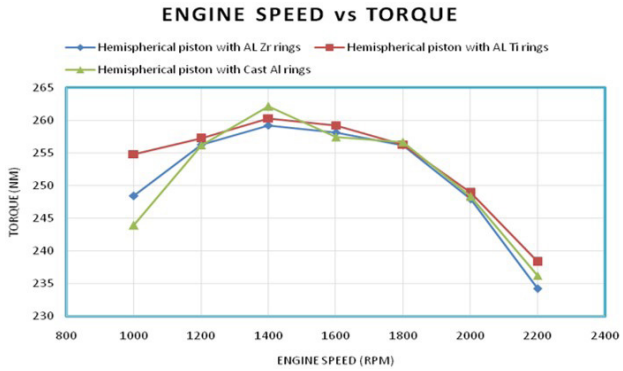


Figure 5: Torque vs Engine speed.

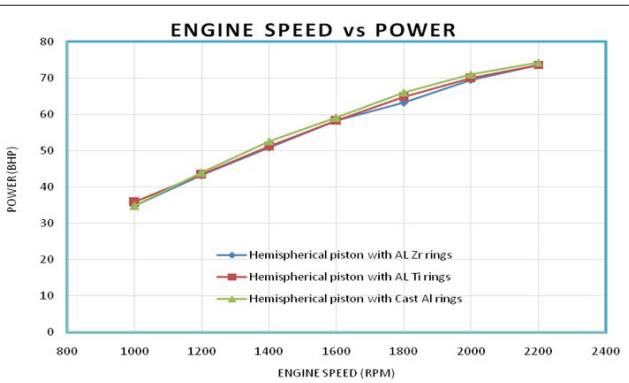


Figure 6: Power vs Engine speed.

hemispherical piston exhibits a notable increase in comparison to alternative combinations at 1400 rpm. Figure 6 illustrates the relationship between speed and power performance. This graph presents a comparison between the utilization of a hemispherical piston in conjunction with three different materials: aluminum-zirconium, aluminum-titanium, and cast aluminum. The analysis focuses on the engine's performance at an angular position of 18 degrees prior to reaching the top dead center. The combination of cast aluminum rings and aluminum-titanium with hemispherical piston exhibits superior power in comparison to alternative combinations. The power output of a hemispherical piston made with aluminum-zirconium is comparatively lower than that of other piston material combinations.

Figure 7 presents a comparative analysis of smoke levels for several combinations of hemispherical piston with aluminum-titanium, aluminum-zirconium, and cast aluminum

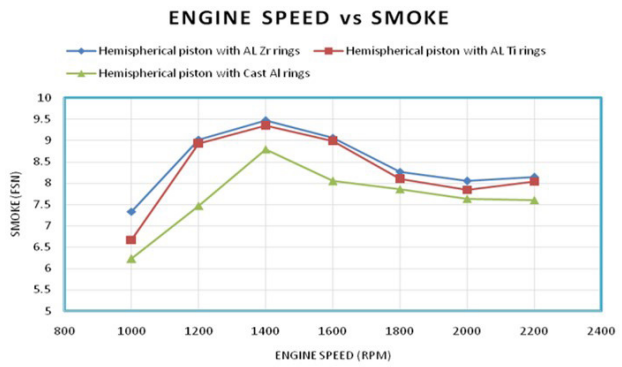


Figure 7: Smoke vs Engine speed.

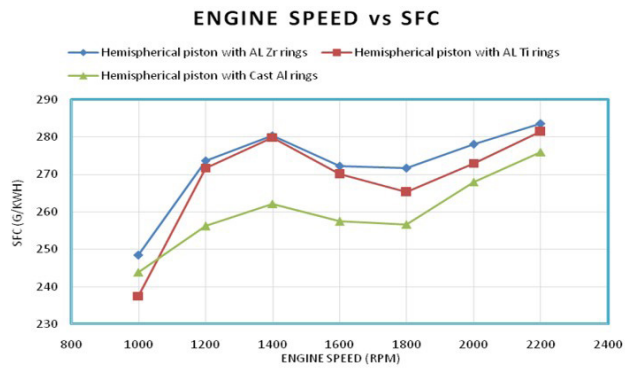


Figure 8: Specific fuel consumption vs Engine speed.

rings, specifically at a crank angle of 18 degrees. The utilization of hemispherical piston with cast aluminum rings results in reduced smoke emissions in comparison to alternative combinations. Figure 8 presents a comparison of specific fuel consumption for various combinations of hemispherical piston with aluminum-titanium, aluminum-zirconium and cast aluminum rings at a crank angle of 18 degrees. The cast aluminum ring with a hemispherical piston has a lower Specific fuel consumption in comparison to alternative combinations.

Conclusion

During the experimental evaluation, a four-cylinder diesel engine was subjected to testing using a hemispherical piston equipped with different piston rings. The objective of this assessment was to analyze the engine's performance. Subsequent observations were made throughout the testing process. When the engine is set at 18 degrees before the top dead center, the hemispherical piston equipped with aluminum-titanium ring exhibits superior torque performance, but the hemispherical piston with cast aluminum rings has inferior torque performance. In comparison to all other combinations, the utilization of a hemispherical piston in conjunction with cast aluminum rings exhibits a higher power output. In comparison to alternative combinations, it has been observed that cast aluminum rings in conjunction with hemispherical pistons have a reduced emission of smoke.

Acknowledgements

None.

Conflict of Interest

None.

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