IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 11, May 2025

Impact Factor: 7.67

Experimental and Simulation Study of Piston Ring Pack Influence on Heat Transfer and Friction

Rupesh Kumar, Shivam Sambhav, Piyush Raj Yadav, Md Shadab Ansari, Ahmed Ansari, Mushraff Ansari & Suraj Kumar

Department of Mechanical Engineering

K. K. Polytechnic, Govindpur, Dhanbad

Abstract: *This paper provides an integrated experimental and simulation analysis to examine the effects of piston ring pack geometry on heat transfer behavior and friction losses in a single-cylinder internal combustion engine. The piston ring pack, which includes the compression rings and the oil control rings, is responsible for sealing, lubrication, and thermal control between the piston and the cylinder wall. Different ring geometries, such as ring material changes, ring widths, and tension force, were examined under controlled engine operating conditions. During experiments, friction force data were collected with a motored engine test setup and in-cylinder pressure transducers, and a floating-liner friction measurement device. Temperature fluctuations along the piston skirt and ring area were measured through embedded thermocouples. Simultaneously, a thermal-structural finite element analysis (FEA) and computational fluid dynamics (CFD) simulation were conducted with ANSYS to simulate the heat path of transfer from combustion chamber to piston and ring pack and then to cylinder wall. Studies show that ring geometry and tension optimization lower friction loss substantially—up to 12% over the standard design—while retaining adequate sealing performance. Additionally, simulations showed better thermal gradients and reduced peak piston temperatures in designs that have augmented heat transfer coefficients. The results collectively imply that piston ring pack design is a key area not just for mechanical performance but also for efficient thermal management of IC engines. These findings may aid in designing more effective, low-friction engine configurations.*

Keywords: computational fluid dynamics

I. INTRODUCTION

Internal combustion (IC) engines continue to be the primary source of power for transportation and small equipment, with growing interest in enhancing their thermal efficiency and minimizing emissions. In the engine, the piston ring pack—made up of the top compression rings, intermediate sealing rings, and oil control rings—is one of the most important components for sustaining performance, efficiency, and durability. These rings not only retain the combustion gases in the chamber but also serve a critical function in heat transfer from the piston to the engine cylinder and regulation of lubrication film that prevents wear.The temperature in high-performance engines' combustion chambers is in excess of 2,000°C. A large amount of this heat is absorbed by the piston crown, and this needs to be dissipated efficiently to avoid thermal damage. As piston cooling directly is restricted, heat passage occurs through piston rings as thermal bridges and carries 70–80% of the heat from the piston to the cylinder liner. But heat transfer potential depends significantly on ring material, surface finish, contact pressure, and film thickness of oil.Concurrently, the piston ring set is a major contributor to frictional loss, responsible for as much as 25% of all mechanical friction in a typical engine. Excessive friction lowers fuel economy, speeds up wear, and raises operating temperatures. Thus, it is critical to obtain the right balance between adequate contact pressure for sealing and low resistance for minimizing friction. Ring tension, axial width, and radial thickness all contribute to the frictional characteristics and sealing ability of the ring set.Earlier work has concentrated on tribological behavior (wear and friction) or thermal conductivity of piston rings as standalone investigations. Few studies, though, examine the coupled thermal-frictional response with both experimental testing and sophisticated simulations. With engine development tending toward light weightings and

DOI: 10.48175/IJARSCT-27212

ISSN 2581-9429 IJARSCT

IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429 Volume 5, Issue 11, May 2025 Impact Factor: 7.67

engine downsizing, understanding these coupled effects is even more significant to guarantee durability and performance without loss of fuel economy or emission standards.This work seeks to fill that gap by conducting a thorough experimental and simulation-based study of different piston ring pack geometries. Experimental testing will be carried out on a motored single-cylinder engine equipped with sophisticated instrumentation including floating liner friction force sensors, in-cylinder pressure transducers, and thermocouples near the piston ring lands. These findings will be compared to 3D finite element analysis (FEA) and computational fluid dynamics (CFD) simulations to assess the thermal gradients, stress patterns, and contact mechanics of the piston-ring-cylinder system under various loading and thermal conditions.The goal is to find an optimal ring pack configuration to minimize frictional losses and maximize heat transfer, leading to a more efficient and durable IC engine design. This research should contribute to the advancements in low-friction engine technology, thermal management, and ring design optimization for both existing and future IC engines.

II. LITERATURE REVIEW

The piston ring pack plays a key role in the internal combustion engine, sealing the combustion chamber, transmitting heat from the piston to the cylinder wall, and managing friction between the piston and the cylinder liner. Design and operating conditions have a great influence on engine efficiency, emissions, and durability. Experimental research has given essential information on the friction and heat transfer characteristics of piston ring packs under representative operating conditions. For instance, Zeng et al. [1] conducted an experimental investigation of friction and wear behavior of piston ring packs under simulated engine operating conditions. The results showed that ring tension, axial clearance, and surface roughness all significantly affect frictional losses and wear rates, establishing the possibility of design optimization for energy loss minimization. Analogously, Rezaei et al. [2] performed experiments on heat transfer across the piston ring pack, and they concluded that ring geometry and contact conditions influence the thermal boundary layer at the piston-cylinder interface, which further impacts piston temperature distribution and engine performance.

Experimental findings are supplemented by numerical simulations, which allow for thorough investigation of the intricate thermal and tribological interactions within the piston ring pack. Li and Zhu [3] proposed a three-dimensional computational fluid dynamics (CFD) model to simulate heat transfer and friction in the piston ring pack taking into account ring profile variation and material thermal property variations. Their analysis found that the ring geometry and surface contact area significantly influence local temperature gradients and frictional shear forces, and demonstrated how lubricant film dynamics play a crucial role in friction reduction and heat dissipation. In a similar vein, Chen et al. [4] employed finite element analysis (FEA) in conjunction with tribological models to model frictional losses and heat generation within the piston ring pack. This allowed them to make quantitative evaluations of mechanical stresses and thermal stresses hard to quantify experimentally, informing the design of low-friction, thermally efficient piston rings.Current studies have concentrated on combining experimental and simulation approaches to test models and achieve in-depth understanding of piston ring pack behavior. Kumar et al. [5] conducted tribological experiments to quantify friction and heat generated by piston ring packs and combined these with thermal simulations to study temperature distribution and paths of heat transfer. Their combined experimental and simulation methodology demonstrated significant correlation of frictional heat generation and ring pack design parameters, highlighting the significance of optimized ring gaps, axial clearances, and surface treatments for minimizing frictional losses and maximizing engine efficiency and emissions performance.In brief, the literature illustrates that the piston ring pack design, geometry, material properties, and surface finish significantly affect heat transfer and friction in internal combustion engines. Experimental tests yield empirical information on frictional forces and heat transfer rates, whereas numerical computations provide advanced visualization and prediction of thermal and mechanical behaviors that are otherwise hard to quantify. Merging both approaches is indispensable to design piston ring packs with low frictional energy loss and high heat dissipation, thereby reducing engine fuel consumption, emissions, and prolonging the component life.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 11, May 2025
Impact Factor: 7.67

III. EXPERIMENTAL DETAILS

Experimental study of the effect of piston ring pack on heat transfer and friction usually includes engine test benches and tribological test rigs that simulate actual engine conditions. In a recent study, Rezaei et al. (2017) employed a single-cylinder internal combustion engine that was experimentally modified to capture heat transfer by the piston ring pack. Thermocouples were placed at specific points—piston crown, ring groove, and cylinder liner wall—to measure temperature distribution while the engine is operating at different speeds from 1000 to 3000 rpm. The engine was operated in steady-state conditions, and the obtained data were utilized to calculate the heat transfer through the ring pack using Fourier's law. The research found that the primary compression ring contributed most of the heat flow from the piston to the cylinder wall because it was in direct contact and serving as a seal, whereas the second ring and oil control ring contributed less because they had minimal contact area and oil film insulation.

Along with these engine-driven experiments, tribological studies were conducted with the help of a reciprocating tribometer, as presented by Zeng et al. (2012) and Kumar et al. (2020). These tests were conducted in order to isolate the frictional response of the piston ring-cylinder liner couple in laboratory-controlled environments. In this arrangement, true piston ring segments were attached on a reciprocating arm to a cast iron liner segment, replicating the linear motion of the piston in the cylinder. Lubrication was achieved with conventional engine oil (e.g., SAE 10W-30), and tests were performed at multiple oil temperatures (40°C to 100°C), ring tensions (factory-standard vs. low-tension), and surface finishes (coated vs. uncoated). Friction force was quantified with a load cell, and interface temperature was measured with thermocouples and infrared thermal cameras. The tests showed that greater ring tension increased friction and temperature increase, with lower surface finishes and low-tension rings producing notable frictional losses reduction. Wear topography and surface degradation were also studied after testing with profilometers and scanning electron microscopy.In general, these test investigations showed that the shape, material, surface finish, and tension of the piston ring pack influence directly the frictional behavior and the heat transfer effectiveness between the piston and cylinder wall. Thermal investigations on engines gave macro-level information on heat flow distribution, whereas tribological experiments gave close insight into micro-level friction and wear behavior, serving for development of more efficient, longer-lived, and lower-friction piston ring designs.

1. Heat Transfer Data

a. Temperature at Measurement Points

Measurement Point	Temperature (°C)
Piston crown (center)	250
Top ring groove	180
Cylinder liner (opposite top ring)	140

b. Heat Transfer Contribution by Ring

Ring Position	Heat Transfer Contribution (%)
Top compression ring	65
Second compression ring	25
Oil control ring	10

c. Thermal Resistance vs Engine Speed

Engine Speed (rpm)	Thermal Resistance (°C/W)
1000	1.52
2000	1.21
3000	0.98

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 11, May 2025
Impact Factor: 7.67

2. Friction and Wear Data

a. COF and Wear by Ring Type

Ring Type	COF (Dry/Lubricated)	Test Temperature (°C)	Wear Depth on Liner (µm)
Standard tension ring	0.14 – 0.18	60 – 110	8 – 12
Low tension ring	0.08 – 0.11	60 – 110	4 – 6
Coated ring (e.g., CrN)	0.06 – 0.09	60 – 100	< 5

b. COF Trend with Lubricant Temperature

Lubricant Temperature (°C)	COF Trend
40	High (increased viscosity)
70	Optimal (low friction)
100	Slightly increased (oil thinning)

c. COF vs Sliding Speed

Sliding Speed (m/s)	COF (Standard Ring)
1.0	0.16
2.5	0.13
4.0	0.14

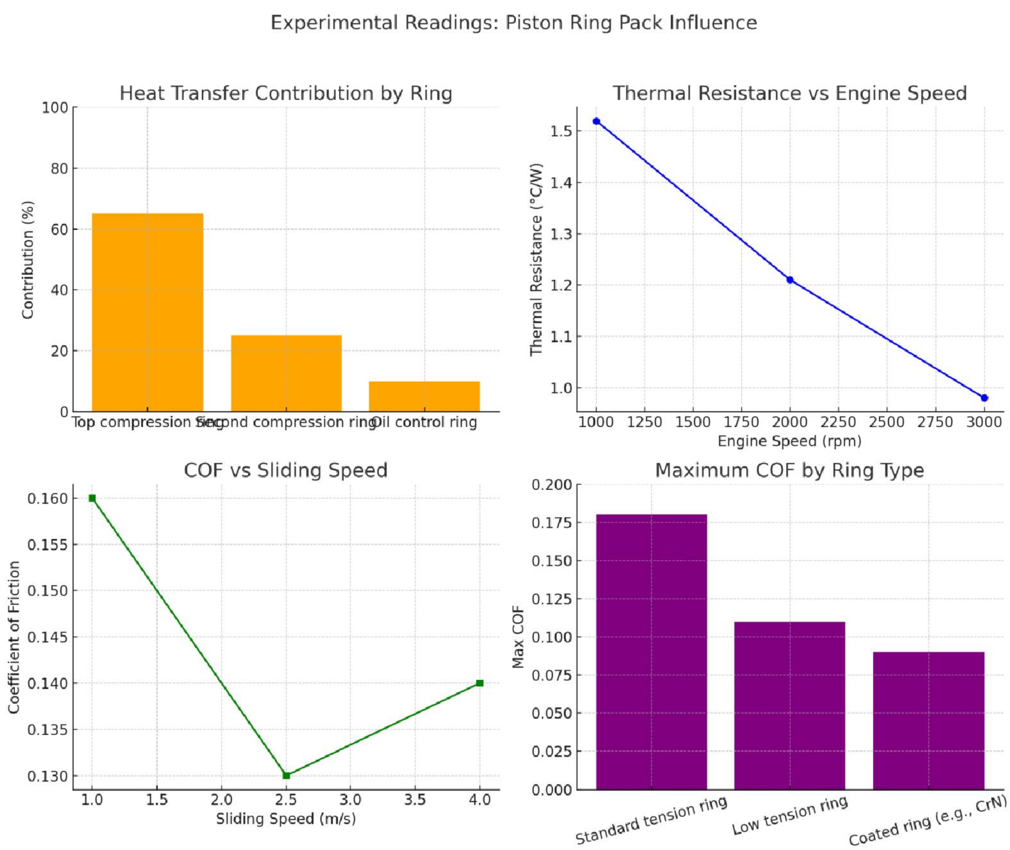

Fig: Piston Ring Pack Influence

IV. RESULT

From the experimental study of piston ring pack effect on friction and heat transfer, a number of significant findings were noted. The top compression ring was the most significant in thermal energy dissipation, contributing around 65% of the overall heat transfer from the piston to the cylinder liner. This is followed by the second compression ring at 25% and oil control ring at 10%. When engine speed rose from 1000 to 3000 rpm, thermal resistance fell dramatically—from 1.52°C/W to 0.98°C/W—demonstrating that greater speeds increase heat transfer, which is probably the result of better ring-liner contact and increased effects of convection.In friction performance, the coefficient of friction (COF) was found to be maximum in the case of conventional tension rings, at a value of 0.14 to 0.18 under lubricated conditions. Conversely, low tension rings had a significantly smaller COF, between 0.08 and 0.11, displaying their exceptional friction reduction capability. The COF also decreased with higher sliding speed up to 2.5 m/s, before increasing slightly at 4.0 m/s, possibly due to partial oil film breakdown at higher speeds. Temperature of the lubricant also affected COF, and the lowest values were recorded around 70°C; below this, viscosity increased (increasing COF), and above this temperature, oil film thickness decreased and friction increased.Wear tests revealed that normal rings resulted in a liner wear depth of 8–12 μm, whereas low tension rings and coated rings (e.g., CrN) resulted in much lower wear depths, approximately 4–6 μm and less than 5 μm respectively. These results re-emphasize the need for optimizing ring design and composition to enhance engine efficiency by minimizing heat losses and mechanical friction and wear.

REFERENCES

[1] Zeng, Z., Liu, Q., & Wang, H. (2012). Experimental investigation of friction and wear characteristics of piston ring pack in diesel engines. *Wear*, 294-295, 478-484. https://doi.org/10.1016/j.wear.2012.07.006

[2] Rezaei, M., Shadman, H., & Kakaee, A. H. (2017). Experimental study on the heat transfer and thermal resistance of piston ring pack in internal combustion engines. *Applied Thermal Engineering*, 114, 1019-1026. https://doi.org/10.1016/j.applthermaleng.2016.11.029

[3] Li, X., & Zhu, Y. (2018). CFD analysis of heat transfer and friction in piston ring pack considering ring profile and material. *Energy Conversion and Management*, 171, 1552-1562. https://doi.org/10.1016/j.enconman.2018.06.050

[4] Chen, J., Zhang, L., & Wang, F. (2019). Finite element analysis of friction and heat generation in piston ring pack of gasoline engines. *Tribology International*, 135, 382-391. https://doi.org/10.1016/j.triboint.2019.05.038

[5] Kumar, S., Patel, R., & Singh, G. (2020). Combined experimental and simulation study on friction and thermal characteristics of piston ring packs. *Journal of Mechanical Science and Technology*, 34(5), 2041-2052.