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EXPERIMENTAL INVESTIGATION ON PERFORMANCE ENHANCEMENT OF A 4 STROKE PETROL ENGINE TEST RIG USING LASER TEXTURED AND TIN COATED PISTON RINGS

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Research Paper

ABSTRACT

Frictional losses at the piston ring–cylinder liner interface account for a significant portion of mechanical losses in internal combustion engines, directly affecting fuel efficiency, emissions, and component durability. Surface engineering techniques such as laser surface texturing (LST) and hard coatings have emerged as effective approaches for mitigating these losses. In the present work, an experimental investigation is carried out on a four stroke, four cylinder petrol engine test rig to evaluate the combined influence of laser textured and titanium nitride (TiN) coated piston rings on engine performance. Two configurations are examined: conventional piston rings and laser textured piston rings with TiN coating. Engine performance parameters including brake thermal efficiency, brake specific fuel consumption, and mechanical efficiency are measured under varying engine speeds and loads. The results demonstrate that laser texturing enhances lubricant retention and stabilizes the oil film, while TiN coating improves surface hardness and wear resistance. The combined LST + TiN treated piston rings exhibit the most significant performance improvement, showing reduced frictional losses and enhanced thermal efficiency compared to conventional rings. The study confirms the synergistic potential of surface texturing and TiN coating for improving performance characteristics of petrol engines.

KEYWORDS: Piston Rings, Laser Surface Texturing, Tin Coating, Petrol Engine, Friction Reduction, Engine Performance

1. INTRODUCTION

Internal combustion engines (ICEs) continue to play a dominant role in automotive and industrial power generation despite the growing interest in electrification. Improving engine efficiency and reducing emissions remain critical objectives, particularly as global emission regulations become increasingly stringent. Among the various subsystems of an ICE, the piston assembly—comprising the piston, piston rings, and cylinder liner—contributes substantially to frictional power losses. It is reported that the piston ring–liner interface alone accounts for nearly 20–25% of the total mechanical friction losses in conventional engines.

Piston rings are responsible for sealing combustion gases, controlling lubricating oil, and transferring heat from the piston to the cylinder liner. These functions subject the ring–liner interface to severe tribological conditions characterized by high contact pressures, cyclic loading, elevated temperatures, and mixed or boundary lubrication regimes, particularly near top dead center (TDC) and bottom dead center (BDC). Consequently, friction and wear at this interface significantly influence engine performance, durability, and oil consumption.

Traditional approaches to reducing friction—such as improving lubricant formulations or optimizing ring geometry—have approached their practical limits. As a result, surface engineering methods have gained considerable attention as next generation solutions. Laser surface texturing (LST) introduces controlled micro geometrical features such as dimples or grooves on sliding surfaces, which act as lubricant reservoirs and generate micro hydrodynamic pressure, thereby reducing asperity contact. Hard coatings such as titanium nitride (TiN), deposited using physical vapor deposition techniques, offer high hardness, chemical stability, and enhanced wear resistance under harsh operating conditions.

Although individual benefits of laser texturing and TiN coating have been widely reported, limited experimental work has focused on their combined application under real engine operating conditions. The interaction between surface texture geometry and coating characteristics is particularly relevant for piston rings, which experience reciprocating motion, frequent lubrication regime transitions, and high thermal stresses. Therefore, experimental validation using an actual engine test rig is essential to assess the practical feasibility of this combined surface treatment.

The present study aims to experimentally investigate the effect of laser surface texturing and TiN coating on piston rings using a four stroke, four cylinder petrol engine test rig. Performance parameters of the engine equipped with conventional, laser textured, and laser textured plus TiN coated piston rings are systematically compared to quantify friction reduction and performance enhancement. The findings provide valuable insights into the synergistic role of surface texturing and hard coatings for improving engine efficiency and durability.

2. EXPERIMENTAL SETUP AND METHODOLOGY

2.1 Engine Test Rig Specifications

The experimental investigations were conducted on a four stroke, four cylinder, water cooled petrol engine coupled with an eddy current dynamometer. The engine is representative of medium duty automotive application

2.2 Significance For Experiment Testing:

This study will help make piston rings that last longer and work better, which can lead to better fuel efficiency, lower emissions, and better engine performance.

EXPERIMENTAL SET UP

Experimental set up four strokes four cylinder 1.1 ltr. Petrol engine test rig

- Test Conditions:
  - Engine speed: 900-1500 rpm
  - Load: 0.5 kg to 4.5kg
  - Oil temperature: 80-120°C
  - Coolant temperature: 80-90°C

- Measurement Parameters:
  - Friction torque
  - Oil consumption
  - Engine performance parameters (e.g., power, efficiency)

2.3 Surface Modification of Piston Rings

Two different piston ring configurations were evaluated:

1. Conventional unmodified piston rings (baseline)
2. Laser textured piston rings with TiN coating

Laser surface texturing was performed on the piston ring face using a pulsed fiber laser to generate uniformly distributed micro dimples. The selected texture parameters were optimized based on literature. These textured serve as lubricant reservoirs and promote micro hydrodynamic pressure generation during sliding motion.

Following texturing, TiN coating was deposited on selected rings using a physical vapor deposition (PVD) process. A thin Ti interlayer was used to enhance adhesion between the substrate and coating. The TiN coating thickness was maintained in the range of 3–5 μm to ensure adequate wear resistance without altering ring geometry or sealing performance.

2.4 Test Setup Description

The test rig consists of:

1. A four-cylinder petrol engine mounted on a rigid test bed and coupled directly to a three-phase AC generator (dynamometer).
2. A fuel burette (500 ml capacity) connected to the fuel line for consumption measurement.
3. Electrical parameters monitored via voltmeter, ammeter, and wattmeter, with a constant power factor of 0.9.
4. Engine speed recorded using a digital tachometer.
5. Exhaust and calorimeter temperatures measured via thermocouples.
6. All instruments were calibrated prior to testing to ensure data accuracy.

2.5 Testing Procedure

- Pre-Start Inspection

Before starting the test, the system was thoroughly checked for leaks, wiring issues, and safety compliance. The fuel burette was filled to 500 ml, and the ignition and lubrication systems were inspected. All generator load switches were kept OFF.

- Warm-Up Phase

The engine was started and allowed to idle for approximately 8–10 minutes until steady operating conditions were reached. Oil pressure, exhaust color, and sound were observed. Ambient temperature and barometric pressure were noted.

- No-Load Test

At no-load, engine speed and fuel consumption were recorded by timing the fuel drop for 10 ml using a stopwatch. Temperatures were noted and readings repeated three times for averaging.

- Load Test

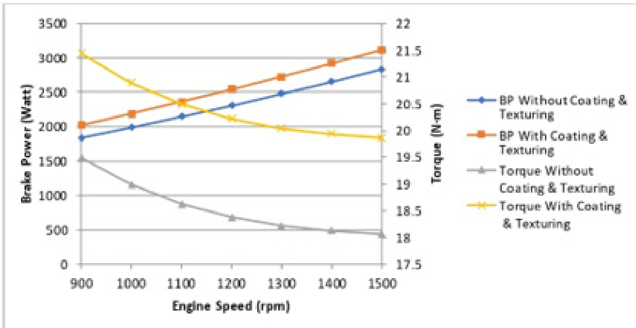
Load was applied progressively in steps of 0.5 kW, 0.75 kW, and 1.0 kW on one phase of the generator. At each load setting, voltage, current, power factor, fuel rate, and temperature were measured. Engine speed was maintained near 1500 rpm. Tests were repeated thrice for accuracy. At higher loads, engine stalling tendencies were noted due to limited torque at low rpm.

- Post-Coating Test

After baseline testing, piston rings were replaced with TiN-coated rings using a controlled coating process. The engine was reassembled, and all tests were repeated under identical conditions.

3. RESULTS AND DISCUSSION

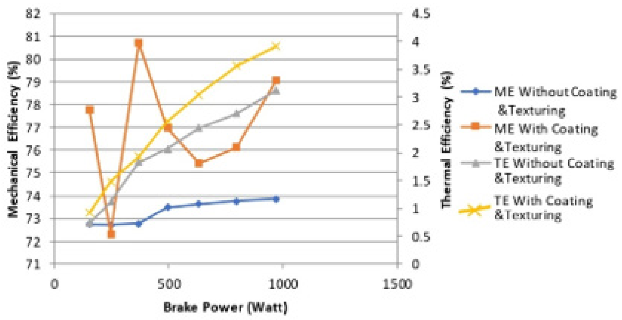
3.1 Effect on Brake power, Torque at Different Engine Speed with &without coated and textured piston ring



Graph 3.1 Brake Power & Torque vs. Engine Speed

At the lowest load of 0.5 kW, the dual graph illustrates a steady rise in brake power (BP) and torque as engine speed increases from 900 to 1500 rpm. Without coating, BP moves from 153 W at 900 rpm to 970 W at 1500 rpm, while torque climbs from 1.62 N·m to 6.18 N·m. With the application of coating & texturing, there is a marked enhancement, as BP rises from 168 W up to 1067 W and torque improves from 1.78 N·m to 6.80 N·m across the same speed range. This improvement, typically ranging from 10–15%, highlights the ability of the coating & texturing to reduce friction and thermal losses, particularly at higher RPMs where such effects are more pronounced. The coated & textured engine operates more efficiently, with mechanical and thermal advantages evident throughout the operating span.

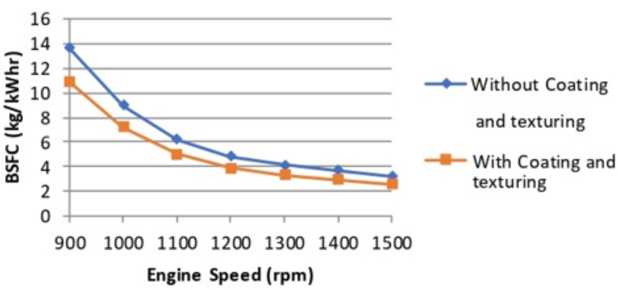
3.2 Effect on Mechanical Efficiency, Thermal Efficiency with &without coated and textured piston ring



Graph 3.2 Brake Power vs Mechanical & Thermal Efficiency

At the 0.5 kW load condition, mechanical efficiency without coating starts at approximately 72.7% at a brake power (BP) of 153 W (900 rpm) and climbs gradually to 73.9% at nearly 970 W (1500 rpm). With coating & texturing, all efficiency metrics improve, with mechanical efficiency rising to around 79.1% at the upper BP limit of 1067 W. Thermal efficiency shows a similar upward pattern, increasing from around 0.7% without coating & texturing to nearly 3.9% with coating & texturing as BP intensifies. The dual graph shows coating's key role in reducing mechanical losses and enhancing thermal energy conversion even at low loads

3.3 Effect on BSFC at Different Engine Speed with &without coated and textured piston ring



Graph 3.3 BSFC vs Engine Speed

The BSFC values for the uncoated & untextured engine start high at around 13.6 kg/KWhr at 900 rpm and decline progressively to approximately 3.21 kg/KWhr at 1500 rpm. The coated & textured engine exhibits consistently lower BSFC across the speed range, beginning around 10.87 kg/KWhr and falling to 2.56 kg/KWhr at 1500 rpm. This reduction shows that coating & texturing significantly improves fuel efficiency, especially at higher engine speeds by reducing friction and improving thermal transfer

4. CONCLUSION

The current study examined the performance improvement of a four-cylinder, four-stroke MPFI petrol engine via the synergistic use of Titanium Nitride (TiN) coating and laser surface texturing (LST) on piston rings. An extensive experimental investigation was conducted utilizing an electrical dynamometer to evaluate the brake power, indicated power, and torque characteristics of the engine prior to and after surface modification. Based on the experimental results, we can come to the following conclusions:

1. TiN coating and LST make brakes work much better in all load conditions.
The brake power with coated and textured rings was always higher than that of uncoated rings, no matter how fast the engine was running (900–1500 rpm)
When the load is 0.5 kW, the improvement is about 8–12%.
This shows that TiN coating and LST lower boundary friction and make combustion more efficient.

2. The indicated power goes up a lot with rings that are coated and textured.
The results of the cut-off test show that the indicated power for coated rings has been steadily rising.

- Gains usually between 5% and 12%, depending on how much weight and speed.
- Indirectly, higher indicated power showed that the cylinder pressure was holding up better.

This is because the lubrication film is more stable, the ring and liner wear is less, and the sealing is better.

3. The torque output gets better across the whole operating range
The coated rings made more torque in both low-load and high-load situations:
Better: 5–10% at most speeds.
The most torque improvements happen between 1300 and 1500 rpm.
The structures made by LST hold oil and help make hydrodynamic pressure higher.

4. The combination of LST and TiN coating works better than just one of them.

When coating and micro-texturing were used at the same time, the following happened:

- Better oil retention
- Stronger hydrodynamic lubrication
- Less asperity contact
- Longer life for piston rings

5. FUTURE SCOPE

This study successfully illustrates performance enhancement via TiN coating and LST; however, subsequent research directions are advised:

1. Study of various coating substances

Subsequent research may investigate alternatives such as:

- Chromium nitride (CrN)
- Diamond-like carbon (DLC) coatings
- Coatings of molybdenum disulfide (MoS_2)
- Nano-coatings made of composites

These materials have one-of-a-kind mixes of hardness, lubricity, and resistance to heat.

2. Fine-tuning the settings for laser surface texturing

The current study employs a constant dimple size and density. Optimization may involve:

- Altering dimple diameter and depth
- Modifying dimple distribution (central, edge-biased, random)
- Investigating elliptical or chevron textures
- Examining patterns of interaction between different textures

This can help you find the best texture geometry for the best lubrication.

3. Testing under conditions of high-speed and high-temperature engines

The current study is constrained to 1500 rpm due to dynamometer limitations. In the future, testing could go up to:

- 3000–5000 rpm
- full-throttle operations
- high-temperature boundary lubrication conditions

This would give a more accurate picture of how a real car engine works.

4. Testing for long periods of time

A long-term study is required to assess:

- Wear rate of TiN coating
- Texture degradation
- Carbon deposit formation
- Blow-by characteristics over thousands of cycles

This will show that the coating is strong and cost-effective.

5. Studies that compare multiple cylinders

More work could involve:

- Diesel engines
- Engines with a high compression ratio
- Petrol engines with a turbocharger
- Experiments with only one cylinder

This will help make the results of other types of engines more general.

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