Effect of Picosecond Laser Texture Surface on Tribological Properties on High-Chromium Steel Under Non-lubricated Conditions

Sushant Bansal, Ayush Saraf, Ramakant Rana, and Roop Lal

Abstract The objective of this paper is to analyse the significant effects of negative dot patterned laser texture on piston ring material under non-lubricated conditions. The aim is to carry out experiments to study the tribological behavioural dynamics of the working on the interface of the textured silver steel piston ring material and EN-31. The percentage of the area of the pin textured, of the total area of the pin surface available, was 41.50%. With the predefined working parameters for the experimental working, such as the load applied, sliding velocity and the track distance travelled over the course of wear for different diameters of specimens used, the values of wear, coefficient of friction and the variation in temperature throughout the experimental duration was measured. The pin and disc interface was not provided with lubrication, and the experiment was run under dry conditions. This experimental study is helpful in the better understanding of the potential of the negative texturing on the surface, leading to the reduction in friction and enhanced wear resistance for IC engines' piston and cylinder interface.

Keywords Tribology · Texture · Wear · Friction · Steel

1 Introduction

The objective of this review is to provide the analysis of the significant effects on high-chromium steel as piston ring material subjected to various tests. Several researches have been carried out to observe the variations in the effect of the working of the steel material when observed with respect to another material such as EN-31 or EN-34 or other materials for improvement in certain properties such as friction resistance, reduction in material wear, lesser heat generation that directly affect the working

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R. M. Singari et al. (eds.), *Advances in Manufacturing and Industrial Engineering*,
Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-15-8542-5_22

life of the material and the output of the working of the material [1–4]. Mainly, the researches that have been carried out earlier were conducted under lubricated conditions, over the material contact surface under testing. These are the prime parameters since life of an engine is dependent on its losses and wear experienced by it, during functioning [5–9].

Previous studies show the response of tribological parameters on the steel when tested under lubricated conditions without any modification in the physical surface property at the area of contact testing [10–14]. The largest source of frictional losses in the internal combustion engine is cylinder and piston system which comprises early 50% of the total frictional losses. The piston rings contribute 70–80% of friction in the cylinder and piston system. Thus, the cylinder and piston system being the paramount needs optimization to achieve high efficiency [15–19].

In order to study the possibilities of optimization of the piston cylinder, an experimental examination is important to study the aforementioned tribological characteristics. Henceforth, the pin and disc setup is considered to observe and study the effects of the materials in contact. The pin material represents the piston ring while the disc represents the cylinder lining. Wear measurements had been carried out and analysed in cylinder and piston ring during their mating with each other when the automotive engine was operated under artificially created dusty environmental conditions. Tests were conducted on pin-on-disc test apparatus with boundary-lubricated cast iron materials, and the values of specific wear rates were observed to be between $10-13$ and $10-10$ mm^3/mm/N. Based on the Newton–Raphson–Murty algorithm, the nonlinear finite element method was used to analyse the piston rings problems based on the theories of elasto-hydrodynamic and hydrodynamic lubrication [20–23].

The pin and disc interface subjected to and worked in worst case scenario conditions which is lack of any lubrication. This was done to ensure the properties of material chosen and the parameters which are varied for increasing the performance of the interface when used as a piston and cylinder interface stay put even if the interface is subjected to the maximum amount of mishandling and is capable of proper functioning as expected till the end of its life span. Due to lack of any kind of lubrication, the interface was subjected to a higher amount of friction than normal working conditions, and the wear observed was higher too when compared to the results observed by other researchers working in similar spectrum but with use of lubrication as well [24–26].

Parameters such as area of contact between the disc and pin had a significant impact on the amount of wear induced in on disc and pin, and a change in the frictional force was observed. Due to usage of negative dotted pattern on pin surface which was formed mainly to reduce area in contact between the pin and disc interface resulted in reduction in friction and hence a important factor in longevity of the life span of the interface when used in applications such as engine cylinders when compared to previous results borrowed from past researches done by fellow researchers [27–29].

2 Morphological Structure and Material Testing

2.1 Specimen Specifications

2.1.1 Preparation of the Specimen Disc

Plain surface finished discs of 100 mm diameter and 8 mm of thickness were produced for experimentation using the casting process, EN-31 was used as the base material for the making of discs, as shown in Fig. 1. The smoothness of the disc surface was ensured by surface grinding of disc surface using a surface grinder, which was followed by rubbing of disc surface against soft belt emery paper which further smoothened out the possibility of any debris and irregularities on the disc surface [30–34].

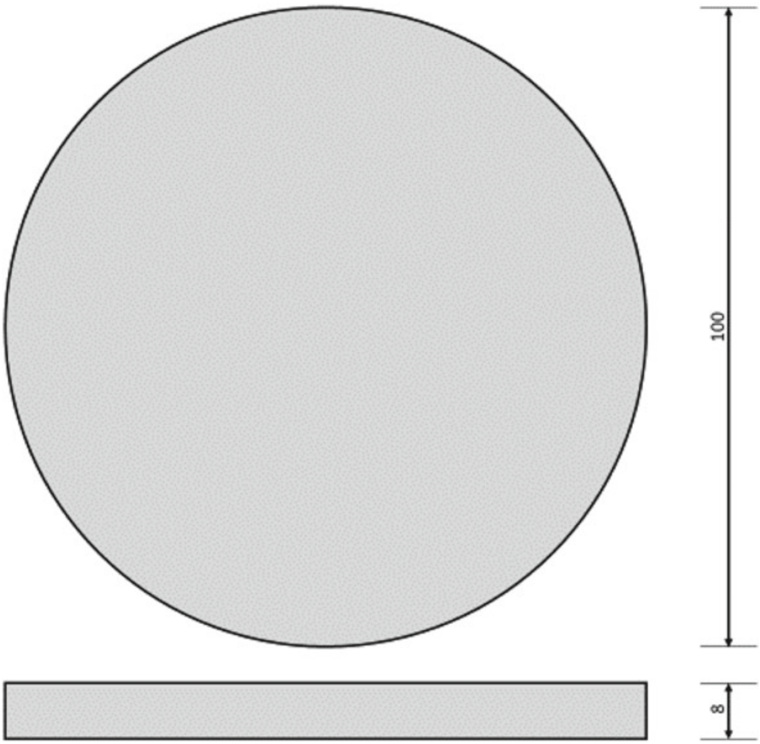

Fig. 1 Schematic diagram for specimen disc (dimensions are in mm)

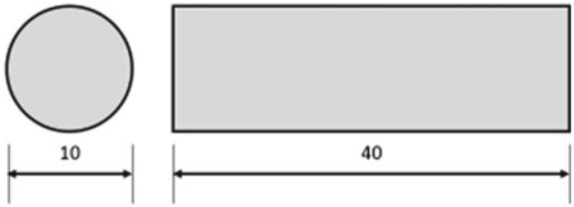

Fig. 2 Schematic diagram for specimen pin without texturing

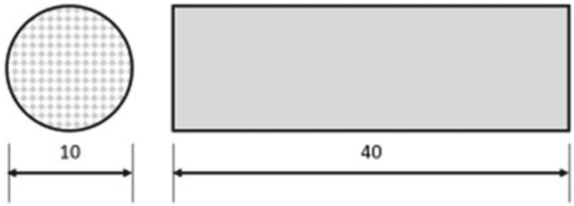

Fig. 3 Schematic diagram for specimen pin with texturing

2.1.2 Preparation of the Specimen Pins

Cylindrical pins of diameters 10 mm and 12 mm with a height of 40 mm each were produced from silver steel material; the surface of these pins was smoothened out by performing surface grinding on pin's circular face to ensure flatness and debris free surface; surface table was used so as to ensure the flatness of the pin surface schematic diagram for which are shown in Figs. 2 and 3 [26, 35, 36].

2.2 Texturing Process

The pins that were used as specimens, of diameters, 10 and 12 mm, after surface finishing was done, were taken under the laser texturing procedure that was carried out on the test surface. The negative dot pattern was grooved on the surface by the picosecond laser texturing machine [37, 38]. Each of the dots formed by this process had a surface depth of 0.2 mm and a diameter of 0.2 mm. Between each dot, there was a distance of 0.25 mm, so as to give the pattern a proper coverage of the surface area that was calculated to be 41.50% of the total finished surface available for the testing. The textured surface of the pin was as shown in Fig. 4.

3 Tribological Test

To emulate the piston and cylinder interface and evaluate the properties like wear resistance and coefficient of friction, tribological test was chosen as it provided a realistic test to simulate the same interface in the form of the pin and disc contact;

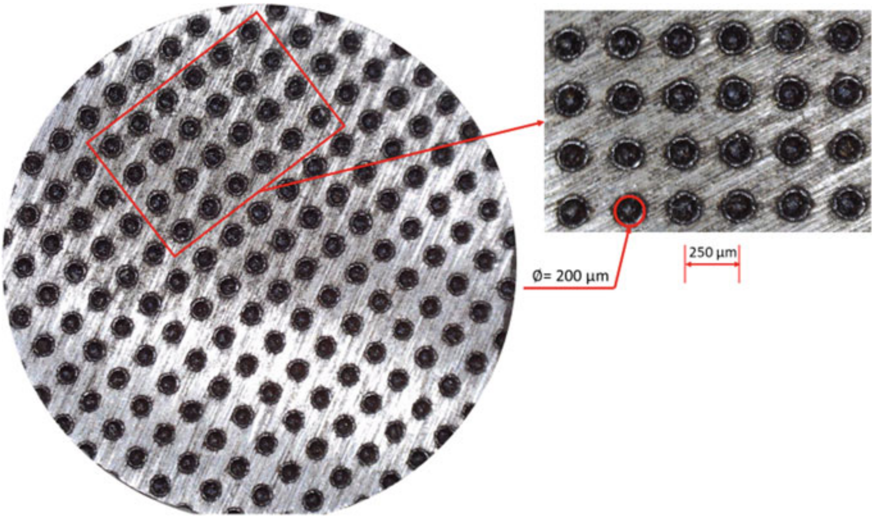

Fig. 4 Textured surface of the specimen pin

pin-on-disc apparatus was used for performing the test; schematic diagram of pin-on-disc apparatus is shown in Fig. 5 along with its top view in Fig. 6; this allowed a continuous sliding contact type testing of interface which is more accurate and effective way of ensuring the results obtained are as realistic as possible [39].

The disc was provided with such provisions so that it could be mounted horizontally onto the pin-on-disc apparatus with the help of four Allen bolts; this ensured secure mounting of the disc while it is rotated at a constant rpm during the test and to maintain it in the horizontal orientation.

Pins were mounted with the help of fixture clamps of different sizes to accommodate different diameters; pins were mounted such that a protrusion of about 4 mm of

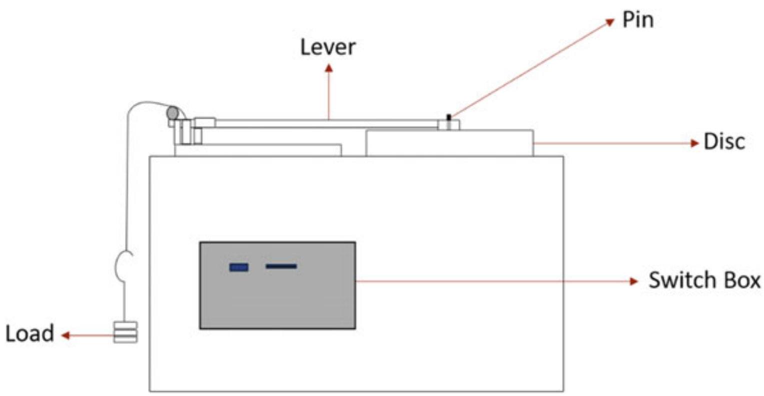

Fig. 5 Schematic diagram of pin-on-disc setup

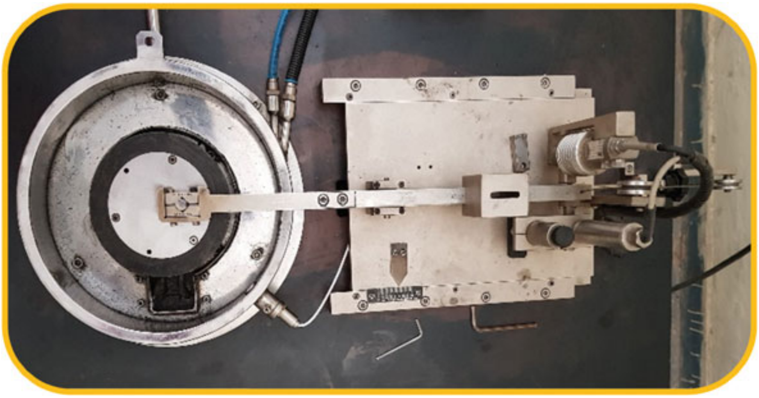

Fig. 6 Top view for pin-on-disc setup used

total length can be obtained outside the fixture for being in contact with the disc so as to avoid the possibility of buckling in pin in the duration of the experiment.

The tribometre which was used for the performance of the experiment was a high-temperature rotary type (TR-20L-PHM800-DHM850) which can rotate the disc from 300–3000 rpm range, it is also capable of providing 20–300 N range of load onto the pin and disc interface.

The test was performed under fixed-parameter conditions; parameters such as sliding velocity of the disc with respect to the pin were 6 m/s, which was kept as constant along with maintaining a constant pressure of 0.26 MPa for tribological performance studies. Observations were made by different track diameter in between the disc and pin interface 50 and 70 mm for pins with diameter 10 and 12 mm, respectively, during which the constant rpm of rotation was calculated and kept equal to 2291 and 1637 rpm for 10 and 12 mm diameters of pins, respectively. The duration of each test was set to be 500 s with total distance traversed by pin onto the disc equal to 3000 m.

4 Results and Discussion

4.1 Wear

Due to continuous sliding contact in between the pin and disc in the duration of the test, the disc and pin experienced certain amount of wear; due to absence of any kind of lubrication, the wear which was experienced was higher than normal. The pressure between the pin and disc contact was kept equal to 0.26 MPa throughout the experiment with the help 30 N of load which was applied initially as a result; the amount of wear which occurred was measured to increase for first 120–140 s

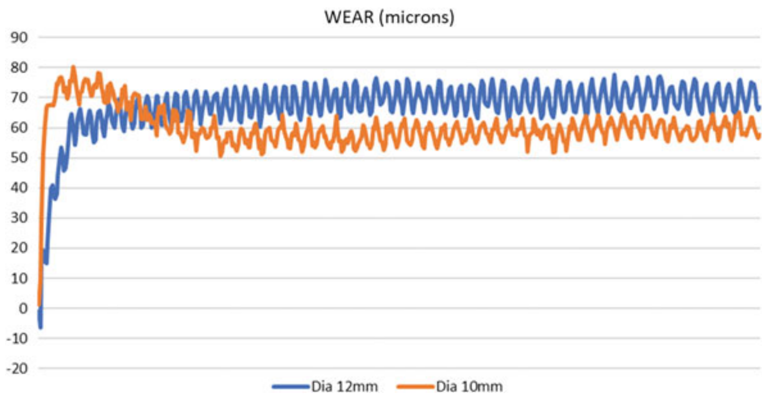

Fig. 7 Wear

from ≈1 micron to a maximum of 80 microns; after the initial time period of the experiment, the amount of wear experienced remained to be nearly constant which is approximately equal to an average of 60.027 microns. The variation of amount of wear which occurred for both specimens has been plotted and shown in Fig. 7 [39].

4.2 Coefficient of Friction (COF)

Whenever there is contact between two identical or different surfaces which are in relative motion with respect to each other, frictional force is developed between the two contact surfaces. This frictional force is governed by the value of coefficient of friction which varies for different material and is also governed by various other factors such as variation in temperature, the presence of abrasives in between contact surfaces. During the tribological test, such variation in values of coefficient of friction was observed, and this variation in the values of coefficient of friction for both the specimens has been plotted and shown in Fig. 8. The average values of coefficient of friction (COF) for silver steel pin specimen of diameters 10 and 12 mm with respect to the EN-31 specimen disc are 1.1594 and 1.1504, respectively.

4.3 Temperature Variation

The heat variation was recorded by the thermography camera, while the tribometre setup was being run for the testing of the specimen. Infrared thermography is the process of detecting, processing and visualizing the invisible infrared radiation that an object emits. The results of the thermography imaging by the imaging camera are as shown in Figs. 9 and 10 [27]. The variation in temperature is a direct result of

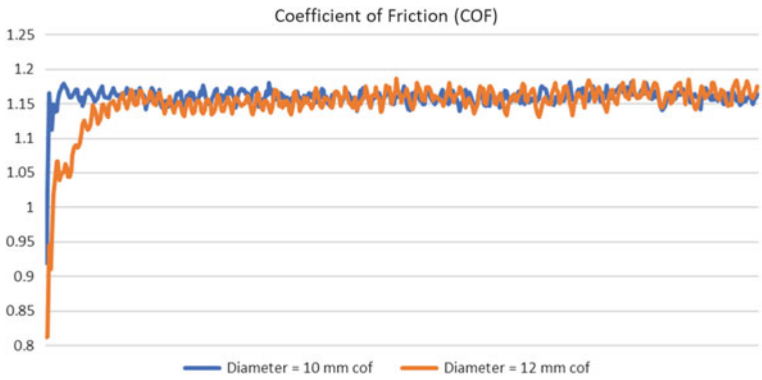

Fig. 8 Coefficient of friction

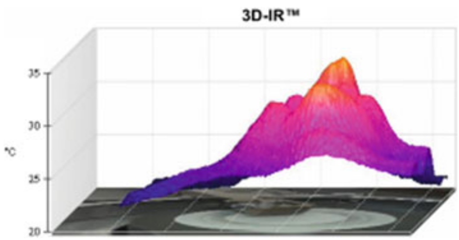

Fig. 9 Thermographic of working setup

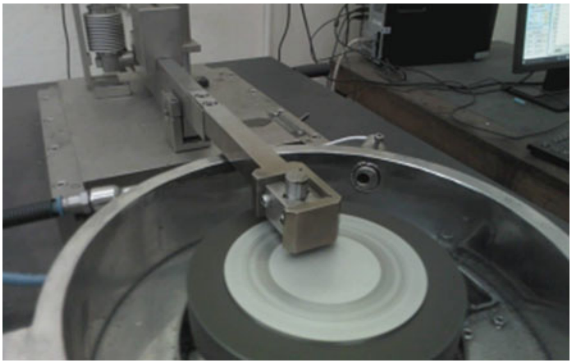

Fig. 10 Image of working setup

the sliding phenomenon which results in generation of frictional forces between the two surfaces of the materials continuously in contact. The factor of no lubrication affects the variation of the temperature in the specimens while continuous running of the tribological test on the pin and disc setup. The image shows the temperature range of the disc during the non-lubricated run of the experiment, i.e. from 34.404 to 38.514 °C.

5 Conclusions

An attempt was made to analyse the tribological behaviour of steel by the means of an experimental investigation on the pin-on-disc test rig. The material of the stationary pin was analogous to the material of piston ring material, while the disc material was EN 31. The tribometre was used to simulate the results in terms of wear and coefficient of friction.

From the experiments, the following conclusions were drawn:

1. The increase in diameter, the pin increases the wear.
2. But, the same diameter has very negligible effect on the coefficient of friction.
3. The textures have significantly improved the thermal dispersions.

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