LASER SURFACE TEXTURING OF EUTECTIC Al-Si ALLOY

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Abstract: Relative movement between piston and cylinder of an IC engine contributes to more than 60% of the friction experienced by the engine - in turn contributing to the wear of the piston and hence loss in its operational performance and efficiency. It is pertinent to explore technological solutions to overcome this situation. Texturing of surfaces appears to be a useful technique to enhance the tribological performance of the piston and cylinder assembly and information about the same are available in published literature. Laser surface texturing of a typical piston material such as an eutectic Al-Si alloy employing high power CO2-CW laser, firstly to examine the magnitudes of optimum laser processing conditions to realize surfaces which can retain oil and secondly to carry out characteristic analysis of the surface quality of the test material subjected to laser texturing, constitute the main thrust of this work. Measurements and analysis of the areal roughness parameters on the laser textured surfaces of the samples on a con-focal microscope reveal their capacity for enhanced oil retention, in turn ensuring reduced chances of scuffing of the sliding surfaces in comparison with non-textured samples, examined under similar test conditions.

Keywords: Laser Surface Texturing (LST); Tribology; Areal Surface Roughness Parameters.

1. Introduction
Automobile Industry continues to remain competitive both in terms of technology and cost. Each opportunity to improve Efficiency, Performance and service life of the components with cost effective methods is highly appreciated. Research endeavours have paved the way to develop components and methods with improved efficiency, performance and service life. Honing the inside surface of the cylinder has been found to create pockets for retaining oil, ensuring reduced levels of friction and wear. The honing of cylinders bores has been traditionally used to reduce friction and wear by creating oil pockets to retain oil for lubrication. This oil is at a risk of being burnt by the combustion gases leading to oil consumption.

2. Literature review
The oil retained in these tiny pockets are also found to be at a risk of getting burnt by the combustion gases leading to enhanced oil consumption. [1]. It is also evidenced that the lubrication oil can be best held in the piston skirt in comparison with the cylinder bore since it will not get exposed to the combustion gases directly[2]. The piston skirt, however, suffers from the side thrust due to the obliquity of the connecting rod which squeezes the lubricating oil present in the gap between the piston and cylinder thus making it to starve from lubrication. Modification of the topology of thrust side surface of the piston skirt by high power lasers appears to be a novel exercise to overcome the cited situation. The benefits derived from such an approach are also available in published information. It has also been found that the laser surface texturing of the piston skirt are stable and lasts longer in comparison with surfaces textured by honing process. Surface texturing has also been employed to produce micro dimples of varying geometries, resembling mini reservoirs and acting as micro hydrodynamic bearings[3,4,5] Laser surface texturing have been found to contribute to frictional reduction in lubricated tribo pairs which are operating under boundary lubrication regime[6,7]. Investigations on laser surface micro texturing of diesel engine cylinders have shown reduction in fuel consumption in comparison with a non textured liner surface under similar loading.
conditions[8]. Several methods are in practice to assess the oil retention capacity of the surfaces. Calculated magnitudes of oil capacity employing different methods appears to be in agreement with the results obtained by employing the family of Sk parameters[9]. Skewness(Rsk) establishes the symmetry of the profile of the surface about the mean line. A surface with equal peaks and valleys will have skewness value of zero whereas the one with more peaks than valleys will have magnitude of skewness which is positive and vice-versa. Surfaces with negative skewness has more bearing surface for sliding which is illustrated by the figure 1. The surface with zero skewness when plateaued can give negative skewness due to decrease in peaks but with no change in valleys. The plateaued surfaces have been known for lower friction having the capacity to hold oil in deep pockets[10]. Earlier results related to assessment of quality of the textured surfaces have also shown that the plateaued surfaces ensures lower friction due to its higher capacity to hold oil in deep pockets[11,12,13]. It is an established fact that the thickness of the oil film is a direct function of the surface roughness of the piston skirt and liners. The thickness of the oil film increases with an increase in the roughness characteristics of the surface[14]. It has also been conclusively evidenced that it is not only possible to selectively texture the surface by a laser but also can achieve consistency of the process[15]. In contrast to the belief that the smoother surfaces possess better scuffing resistances, research investigations have also established that the laser treated lapped surfaces possess better scuffing resistance in comparison with the ground and polished surface subjected to similar conditions of friction and wear[16,17]. Parameters influencing the quality of surfaces are defined schematically in figures 2 and 3.

Fig. 1. Surface profile for Negative and Positive skewness.

Fig. 2. Surface profile and Material ratio curve showing R- parameters
3. Experimental details

3.1 Test Material

Eutectic Al–Si alloy test samples, 15x15x5mm geometry were directly machined out of old pistons of a single 6 cylinder IC engine of a commercial transport vehicle. The geometry of the test sample is shown in fig 4 and the composition in table 1.

Fig 4: Test Sample

Table 1: Chemical Composition

|    | Al  | Si | Cu | Mg | Zn | Ni | Fe | Mn | Na |
|----|-----|----|----|----|----|----|----|----|----|
| Remainder | 11.85 | 1.5 | 1.3 | 1.5 | 1.5 | 0.8 | 0.3 | 0.25 |

The test samples were then ground to ensure an average surface roughness, Ra of 6μm and chemically treated with NaOH of 1N to increase laser absorptivity before being surface textured with a high power CO2 – CW laser.
3.2 Laser Parameters for Surface Texturing

Ground surface of the test samples were first texturized over a range of laser processing parameters viz., power (0.4 to 0.8 kW), beam diameter (0.4 mm to 0.8 mm) and scan speed (0.3 m/min to 2.7 m/min) to establish the basic and critical information about the depth and the quality of the laser textured surfaces. Energy density employed during the texturing process for each combination of the processing parameters in the cited range were computed employing scientific information available in published literature[3], i.e., Energy Density (J/mm²) is calculated as Laser Power (W)/[Beam Diameter(mm) x Scan Speed(mm/s)] and their magnitudes are shown in table 2.

Table 2: Energy Density

| Specimen | Laser Power(kW) | Beam Diameter(mm) | Scan Speed(m/min) | Energy Density (J/mm²) |
|----------|----------------|-------------------|------------------|------------------------|
| 1        | 0.4            | 0.4               | 0.3              | 200.00                 |
| 2        | 0.4            | 0.6               | 2.7              | 14.81                  |
| 3        | 0.4            | 0.8               | 1.5              | 20.00                  |
| 4        | 0.6            | 0.4               | 2.7              | 33.33                  |
| 5        | 0.6            | 0.6               | 1.5              | 40.00                  |
| 6        | 0.6            | 0.8               | 0.3              | 150.00                 |
| 7        | 0.8            | 0.4               | 1.5              | 80.00                  |
| 8        | 0.8            | 0.6               | 0.3              | 266.67                 |
| 9        | 0.8            | 0.8               | 2.7              | 22.22                  |

3.3 Optimization of Laser Parameters

In the first trials, nine (9) test samples were laser textured and the results are tabulated in table 3, which includes the actual photographs of the laser surface textured test samples over a range of laser processing conditions.

Table 3. Lasing Parameters and Surface Photographs

| Specimen | Laser Parameters | Photographs showing the distortion and surface texture of the sample |
|----------|------------------|---------------------------------------------------------------------|
| 1        | Power = 0.4kW    | ![Photograph](image1.jpg)                                            |
|          | Beam diameter = 0.4mm | ![Photograph](image2.jpg)                                          |
|          | Scan speed = 0.3 m/min | ![Photograph](image3.jpg)                                         |
|          | Energy density = 200 J/mm² | ![Photograph](image4.jpg)                                      |
| 2        | Power = 0.4kW    | ![Photograph](image5.jpg)                                            |
|          | Beam diameter = 0.6mm | ![Photograph](image6.jpg)                                          |
|          | Scan speed = 2.7 m/min | ![Photograph](image7.jpg)                                         |
|          | Energy density = 14.81 J/mm² | ![Photograph](image8.jpg)                                      |
|   | Power  | Beam diameter | Scan speed | Energy density |
|---|--------|---------------|------------|----------------|
| 3 | 0.4kW  | 0.8mm         | 1.5 m/min  | 20J/mm²        |
| 4 | 0.6kW  | 0.4mm         | 2.7 m/min  | 33.33 J/mm²    |
| 5 | 0.6kW  | 0.6mm         | 1.5 m/min  | 40J/mm²        |
| 6 | 0.6kW  | 0.8mm         | 0.3 m/min  | 150J/mm²       |
| 7 | 0.8kW  | 0.4mm         | 1.5 m/min  | 80J/mm²        |
| 8 | 0.8kW  | 0.6mm         | 0.3 m/min  | 266.67 J/mm²   |
| 9 | 0.8kW  | 0.8mm         | 2.7 m/min  | 22.22 J/mm²    |

Table 3 clearly reveals that the surface of the test samples 1, 6, 7 and 8 are over melted or distorted, possibly due to higher magnitudes of input energy densities whereas the surfaces of the test samples 2 and 3 appear to have not been discernibly affected by laser texturing process. However in the case of samples 4, 5 and 9, the quality of their surfaces appears to be moderately affected by laser texturing.
process. The magnitudes of the energy densities employed to laser texture the surfaces of these test samples are in the range of 20 to 40 J/mm2, considered as optimum in this work. Accordingly, three new samples were laser textured at powers varying from 0.4 to 0.8kW and scan speeds varying from 2 to 4 m/min at a constant beam diameter of 0.4mm. Energy densities in all the cases were kept constant at 30 J/mm2 which is the mid value between 20 to 40 J/mm2 considered as optimum range in this work. The laser treatment scheme is tabulated in table 4.

Table 4. Laser Texturing with Optimum Process Parameters

| 1. Sample | 2. Laser Power(kW) | 3. Scan Speed(m/min) |
|-----------|--------------------|---------------------|
| 4. 1      | 5. 0.4             | 6. 2                |
| 7. 2      | 8. 0.6             | 9. 3                |
| 10. 3     | 11. 0.8            | 12. 4               |

3.4 Surface Topography Analysis

Surface topology of the laser textured test samples shown in table 2 were captured on a Olympus LEXT OLS 4000 laser con focal microscope. The 3D surface topology of the laser textured test samples and the parameters for assessing the characteristic nature of the surfaces are shown in figs. 5,6 and 7.

Figure 5. Surface Topology (P - 0.4kW, U - 2m/min)

Figure 6. Surface Topology (P - 0.6kW, U - 3m/min)
4. Results and Discussions
Analysis of the topology of the laser textured surfaces of the test samples clearly reveal that the magnitudes of the volume of the voids are 1.171 μm$^3$/μm$^2$, 1.319 μm$^3$/μm$^2$ and 3.254 μm$^3$/μm$^2$ for samples 1(P – 0.4 KW, U – 2 mm/s), 2 (P – 0.6 KW, U – 3 mm/s) and 3 (P – 0.8 KW, U – 4 mm/s) respectively clearly indicating that at identical magnitudes of energy density, input laser power determines the magnitude of the volume of voids with higher laser power facilitating the larger volume of voids which in turn can hold higher quantity of oil during the lubricated tribo process. Further, the volume of peaks per unit area are 0.425μm$^3$/μm$^2$, 0.428μm$^3$/μm$^2$ and 0.326 μm$^3$/μm$^2$ for samples 1, 2 and 3 respectively, probably influenced by the cooling rates encountered during the texturing process, with higher scan speeds of the beam ensuring higher cooling rates- characteristic of the process. Further, the magnitudes of $S_{sk}$, representing the number of valleys on the textured surface are all negative indicating the presence of more number of valleys per unit area compared to number of peaks per unit area clearly suggesting that the textured surfaces have more number of valleys which can hold more oil during the lubricated tribo process and hence contributing reduction in friction and wear. The results of this investigation highlights the novelty of employing high power laser for texturing the surfaces of materials besides suggesting the importance of this technique to realise the much needed techno economic benefits in automobile environments.

5. Conclusions
The results of this investigation reveal the following
Laser texturing of the surfaces of pistons of an IC engine can significantly contribute to their reduced friction and wear. Optimum energy densities, between 20 to 40 J/mm$^2$ appears to be appropriate to realise surfaces which can retain oil during the lubricated tribo process for the test materials used in this investigation. The results of this investigation has considerable relevance and significance in the contexts of employing test samples which are directly machined out from an in service vehicle.

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