Laser Surface Texturing of Aluminium Silicon and Aluminium Bronze to Enhance Tribological Properties

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***Abstract*— An experimental study was carried out to investigate the tribological behavior of different laser surface texture patterns, with Aluminum Silicon, under realistic operating conditions of starved lubrication, for use in automobile components. Compared to un-textured surfaces, the texture patterns showed significant tribological improvements. Various experiments performed also highlight the improvement in surface properties such as hardness and oil retention capabilities which are tabulated using MINITAB and supporting graphs are also plotted.**

Surface texturing has emerged in the last decade as a viable option of surface engineering resulting in significant improvement in load capacity, wear resistance, friction coefficient etc. of tribological mechanical components. Various techniques can be employed for surface texturing but Laser Surface Texturing (LST) is probably the most advanced so far. LST produces a very large number of micro-dimples on the surface and each of these micro-dimples can serve either as a micro-hydrodynamic bearing in cases of full or mixed lubrication, a micro-reservoir for lubricant in cases of starved lubrication conditions, or a micro-trap for wear debris in either lubricated or dry sliding.

Keywords: Laser surface texturing (LST), Minitab, Taguchi.

I. INTRODUCTION

Surface texturing as a means for enhancing tribological properties of mechanical components is well known for many years. Perhaps the most familiar and earliest commercial application of surface texturing is that of cylinder liner honing. Today surfaces of modern magnetic storage devices are commonly textured and surface texturing is also considered as a means for overcoming adhesion and stiction. Fundamental research work on various forms and shapes of surface texturing for tribological applications is carried out by several research groups worldwide and various texturing techniques are employed in these studies including machining, ion beam texturing, etching techniques and laser texturing. Interestingly almost all these fundamental works are experimental in nature and most of them are motivated by the idea that the surface texturing provides micro-reservoirs to enhance lubricant retention or micro-traps to capture wear debris. Usually, optimization of the texturing dimensions is done by a trial and error approach.[1]

Various forms of surface texturing can be used for enhancing tribological performance. However, of all the practical micro-surface patterning methods it seems that laser surface texturing LST offers the most promising concept. This is because the laser is extremely fast and allows short processing time. It is clean to the environment and provides excellent control of the shape and size of the micro-dimples, which allows realization of optimum designs. By controlling energy density, the laser can safely process hardened steels, ceramics, and polymers as well as crystalline structures.[1,2]

Indeed, LST is starting to gain more and more attention in the tribological community as is evident from the growing number of publications on this subject.

The purpose of this paper is to review effects of surface texturing in general and the laser surface texturing in particular. [1,2]

II. EXPERIMENTAL PROCEDURE

Pistons of heavy duty diesel engines were selected to get experimental specimens of Aluminum silicon. The crown of the piston was ideal for making the specimens. The square specimens of 15*15 mm cross-section with depth of 7mm are machined out of piston crown.

Aluminum Bronze alloy which commercially available as rod was cut out into circular disc specimens.

After cutting and machining the specimens were then surface finished with honing stone to obtain an even surface. This was done through honing stones of 320 grit size against which the specimens were rubbed in order to obtain an even grit size on the surface of specimens.

The finished surface thus obtained on Aluminum silicon and Aluminum bronze specimens further underwent etching process with sodium hydroxide (NaOH) keeping 1N of the solution which was prepared by crystals mixed with light warm water around 35-40° Celsius to initiate the reaction at faster rate. The 1N strength of solution was kept in which the square specimens and cylindrical specimens were immersed to carry out the etching process.

The specimens were kept immersed for about 10 minutes to remove all dust, grease and oxides formed on the surface as any impurities will cause effect on experiment results. The immersed specimens were drawn out with the help of tongs and were left to dry out moisture from surface.

As observed was scale formation visible on the surface of specimens. This scale formation was not washed off from the surface as it is helpful in absorption of light and thus will prove to be a positive factor for laser structuring process.
Further the etched specimens thus obtained underwent laser structuring process with two types of lasers. The experiment was conducted on CO2 continuous laser and with Nd:Yag pulsed laser. Aluminum silicon textured with CO2 continuous laser and Aluminum bronze was textured with Nd:Yag pulsed laser. Various ranges of values were selected for each parameter based on data researched on internet. The laser parameters were arranged in such a way that they can be optimized later on basis of Taguchi orthogonal array L9 method. Total 9 tests were conducted which consist of 3 variables with 3 levels of each variable as required by taguchi orthogonal array method.
Further the textured specimens thus obtained underwent oil retention and hardness tests. Afcoset weight measuring machine was used for determining oil retention amount while Vicker's hardness tester with diamond indenter was selected to determine hardness of samples.

The values thus obtained were formulated in a table. These values with respective trial parameters were fed in Minitab software to analyze with taguchi method. The optimized trial values combination for higher hardness and higher oil retention amount was thus determined with help of graphs plotted and S/N (signal to noise) ratios. The optimized combination thus obtained, gives us the higher hardness and large oil retention, which can be used as a final data.

III. SPECIMENS

Following are the specimens with un-textured and textured surfaces after machining.

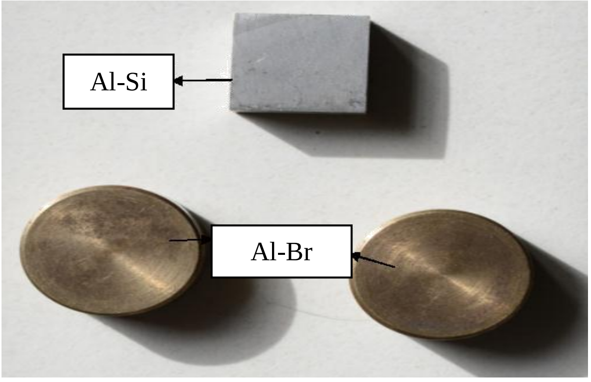

Figure 1: Un-textured specimens

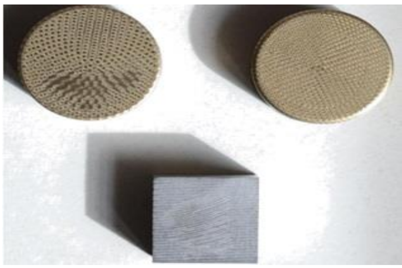
Figure 2: Trial 1 Specimens

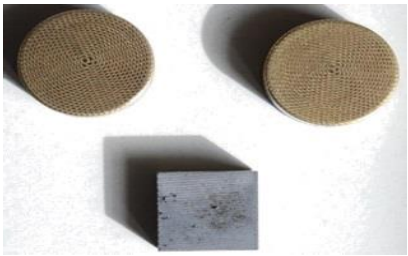
Figure 3: Trial 2 Specimens

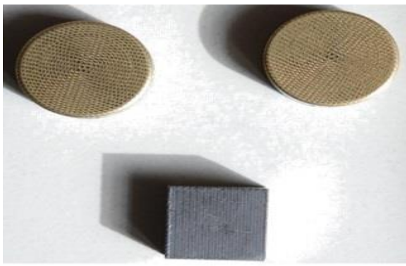
Figure 4: Trial 3 Specimens

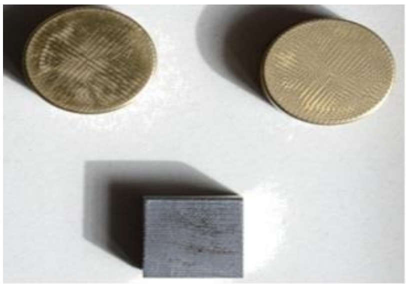
Figure 5: Trial 4 Specimens

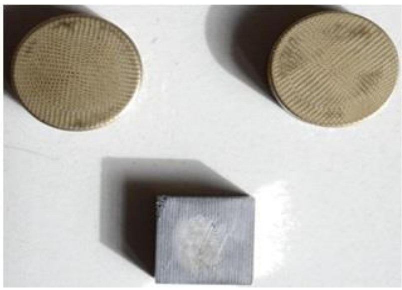
Figure 6: Trial 5 Specimens

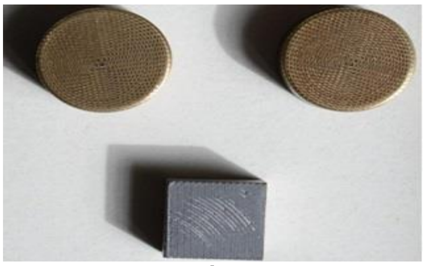
Figure 7: Trial 6 Specimens

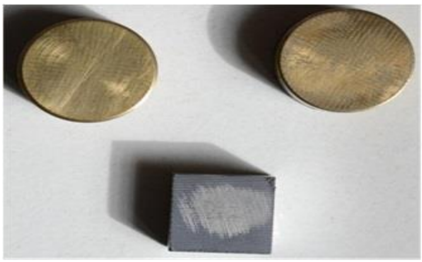
Figure 8: Trial 7 Specimens

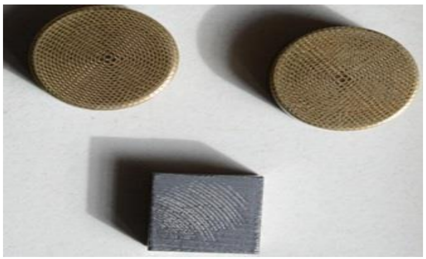
Figure 9: Trial 8 Specimens

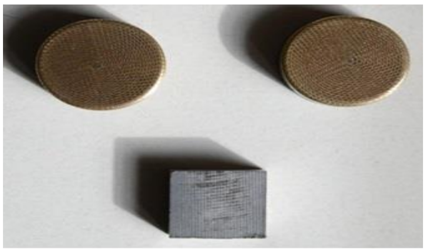
Figure 10: Trial 9 Specimens

IV. SPECIMEN: ALUMINUM-BRONZE (320 HONED)

Laser machine: Nd-Yag Pulsed Laser

Laser parameters:

Power up to 200W
Frequency (Hz): 10, 15, 20
Beam diameter (mm): 0.4, 0.6 0.8
* Speed is kept constant i.e. 2.5 mm/s

Taguchi Array L9 method:

Experiment trials	Power (Kw)	Frequency (Hz)	Beam diameter (mm)	Oil retention (gm)	Hardness (HV)
1	100	10	0.4	0.0046	547.0
2	150	15	0.6	0.0010	503.8
3	200	20	0.8	0.0015	254.2
4	100	15	0.8	0.0005	309.9
5	150	20	0.4	0.0022	367.9
6	200	10	0.6	0.0027	336.9
7	100	20	0.6	0.0024	292.5
8	150	10	0.8	0.0057	400.8
9	200	15	0.4	0.0039	376.1

Figure 11: Taguchi array L9 method for Aluminum Bronze.

a) Oil Retention:

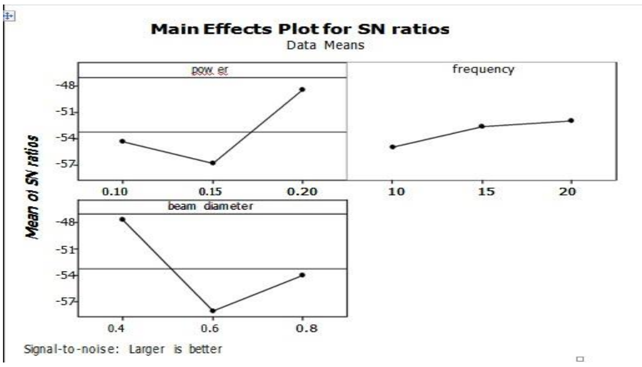

Figure 12: Main effect plots for oil retention.

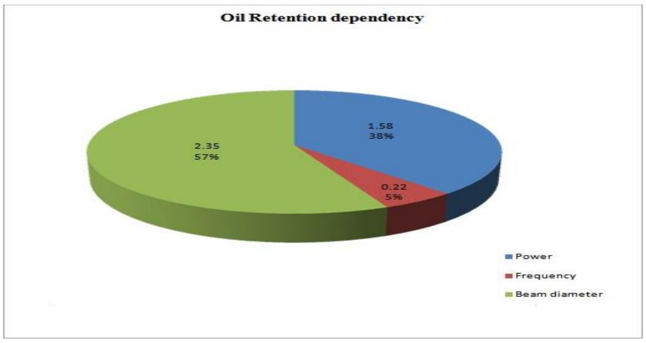

Figure 13: Oil retention dependency factors

b)* *Hardness:

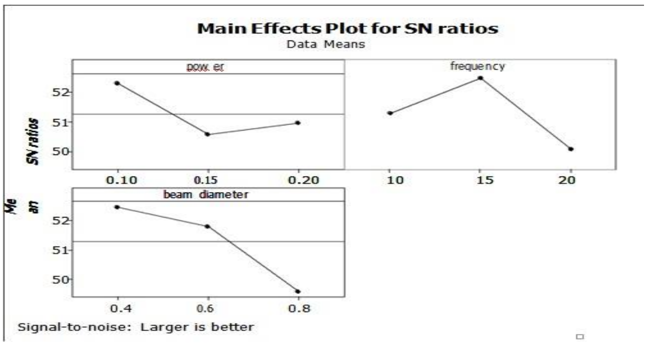

Figure 14: Main effect plot for hardness.

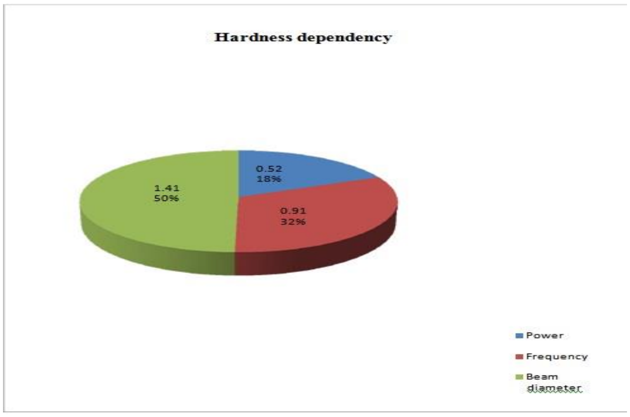

Figure 15: Hardness dependency factors

Significant improvement in the response of the surface in terms of Hardness and Oil retention was observed. The values thus obtained represent the change in properties of surface.
The optimization of the trial values to obtain high hardness and simultaneously more oil retention ability is thus tested in Minitab software taguchi design.

Results and observation:

The Main Effect Plot: The main effect plot for optimized hardness and oil retention are indicated above in graphs. On basis of analysis of S/N ratio the optimized parameters for achieving higher hardness and higher oil retention are as follows:

Higher oil retention: Power- 200 watts, Frequency- 20 Hz, Beam diameter- 0.4mm

Higher hardness: Power- 100 watts, Frequency- 15 Hz, Beam diameter- 0.4mm

The ANOVA analysis: The ANOVA values are considered to estimate magnitude of factors effect on response characteristics. The values of F static after performing ANOVA are tabulated in above table for power, frequency and beam diameter. The table clearly reveals that F value for the oil retention, parameter beam diameter is significantly large than frequency and power. Similarly the F value for the hardness, parameter beam diameter is significantly larger than frequency and power. The corresponding variable percentage contributions of process parameters on hardness and oil retention are tabulated above.

V. SPECIMEN: ALUMINUM-SILICON (320 HONED)

Laser machine: CO2 continuous laser

Laser parameters:
Beam Diameter (mm): 0.4, 0.6 and 0.8
Speed: Up to 4m/min
Power: Up to 3kW

Taguchi Array L9 method:

Experiment trials	Beam diameter (mm)	Speed (mm/s)	Power (kW)	Oil retention (gm)	Hardness (HV)
1	0.5	2.1	0.3	0.0031	283.6
2	0.6	2.7	0.4	0.0041	303.2
3	0.7	3.3	0.5	0.0024	218
4	0.5	2.7	0.5	0.0036	281.4
5	0.6	3.3	0.3	0.0023	360.7
6	0.7	2.1	0.4	0.0021	247.5
7	0.5	3.3	0.4	0.0030	183.4
8	0.6	2.7	0.5	0.0032	132
9	0.7	2.1	0.3	0.0029	158.1

Figure 16: Taguchi array L9 method for Aluminum Silicon.

c)* *Oil Retention:

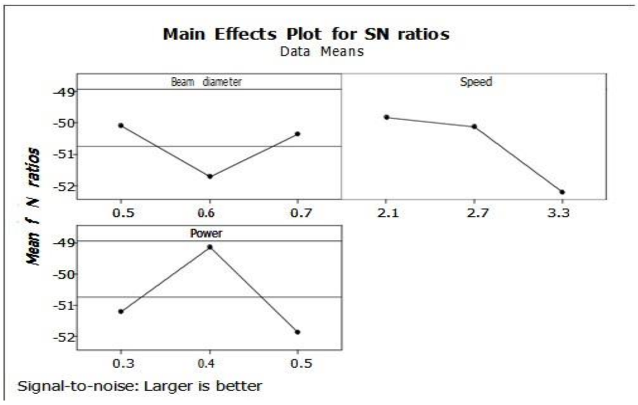

Figure 17: Main effect plots for oil retention.

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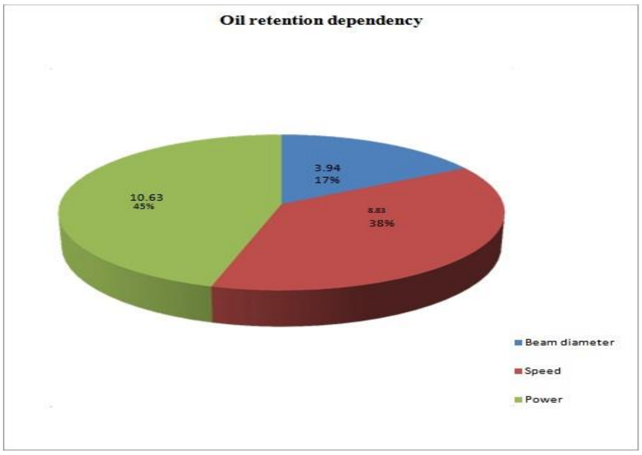

Figure 18: Oil retention dependency factors.

d) Hardness:

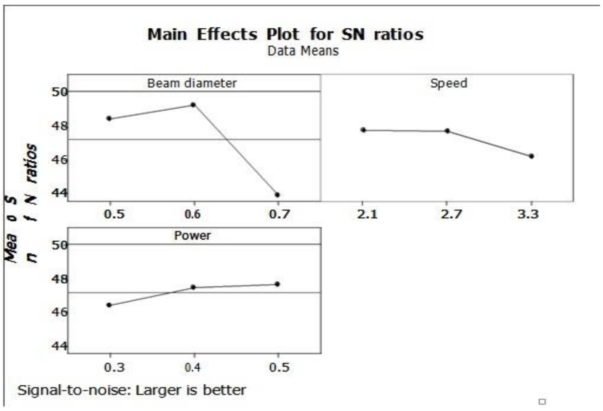

Figure 19: Main effect plot for hardness..

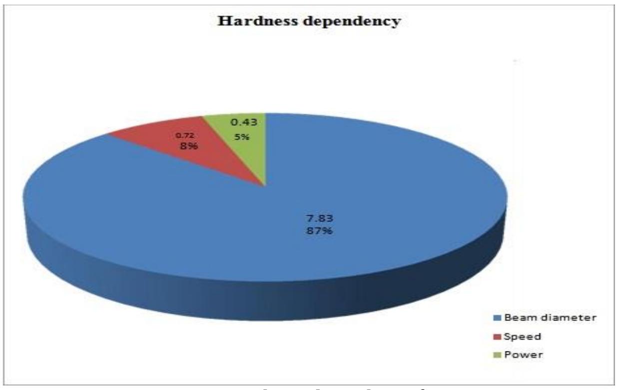

Figure 20: Hardness dependency factors.

Results and Observations:

The Main Effect Plot: The main effect plot for optimized hardness and oil retention are indicated above in graphs. On basis of analysis of S/N ratio the optimized parameters for achieving higher hardness and higher oil retention are as follows:

Higher oil retention: Beam diameter- 0.5mm, Speed- 2.1 mm/s, Power- 400watts

Higher hardness: Beam diameter- 0.6mm, Speed- 2.1 mm/s, Power- 500watts.

The ANOVA analysis: The ANOVA values are considered to estimate magnitude of factors effect on response characteristics. The values of F static after performing ANOVA are tabulated in above table for power, speed and beam diameter. The table clearly reveals that F value for the oil retention, parameter power is significantly large than speed and beam diameter. Similarly the F value for the hardness, parameter beam diameter is significantly larger than speed and power. The corresponding variable percentage contributions of process parameters on hardness and oil retention are tabulated above.

VI. COMPRESSION TEST

The Aluminum Silicon optimum parameters for oil retention obtained from Taguchi array method were employed on IC engine piston skirt to enhance the oil retention capability at the vicinity of piston skirt and to increase the compression pressure within the cylinder.

For this purpose Bajaj Discover 125cc engine's standard size piston was used. The piston was first etched with NaOH 1N solution to minimize the effect of reflection of laser beam due to shiny surface of piston skirt. Pressure within the engine cylinder was calculated before and after the laser surface texturing of piston. The difference noted was relevant.

Texturing parameters for maximum oil retention:
Beam diameter- 0.5mm, Speed- 2.7 mm/s, Power- 500watts

Figure 21: Piston before Laser Surface Texturing

Figure 22: Piston after Laser Surface Texturing

Power and speed of CO2 continuous laser was slightly increased to minimize the loss of power during texturing and enhance the effect of laser surface texturing on piston skirt.

Figure 23: Compression pressure before Laser Surface Texturing

Figure 24: Compression pressure after Laser Surface Texturing

RESULT AND CONCLUSION:

A significant amount of increase in the compression pressure was observed within the cylinder. Before texturing the compression pressure was noted as approximately 4.8 bar while after laser surface texturing the compression ratio increased with a significant amount and was noted to be approximately 7.4 bar. As a result, due to increase in compression pressure we can comment that LST also in different ways promotes towards better fuel efficiency, extended life of piston, cylinder and better lubrication within the cylinder.

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