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Laser Surface Texturing of Leaded Bronze Substrates with Nanosecond Laser

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ABSTRACT: The global laser processing market is accounted for US$ 6.4 Billion in 2017 and is expected to grow at a compound annual growth rate (CAGR) of 6.10% over the forecast period 2018-2024, to account for US$ 9.70 Billion in 2024. But lack of technical complexities in high-power lasers are restricting use of laser processing.This paper discusses the effect of laser surface texturing on leaded bronze material with different density of patterns using nanosecond fiber laser to decrease friction coefficient and improve wear resistance. Thelowest friction coefficient of 0.17 was obtained for 20% texture density at 400 rpm with constant load 1 kg. The laser textured surface had lower and more stable friction coefficient than untextured surface.

KEYWORDS:LST, Pin-on-disc, Sliding speed.

I. INTRODUCTION

The complexity of the tribological properties of materials and the economic aspects of friction and wear justify an increasing research effort. There is an increasing demand to reduce and control friction and wear in order to extend the lifetime of mechanical systems, to improve their efficiency and reliability, to conserve scarce material resources and energy, and to improve safety [1, 2]. This enhanced the efforts to investigate new or advanced materials and surface topography and texture design that improve the tribological performance of friction surface.

Surface texturing is surface modification approach, resulting in an improvement of tribological performance characteristics such as friction and wear resistance. Surface texturing can be performed either as a protruded or recessed asperity, with the latter being more popular due to advantages in terms of micro-lubrication and ease of manufacturing [3].The Various methods to create surface texture such as laser method, micro-EDM, ECM, CNC-ultrasonic method, Focused Ion Beam machining, AJM, Vibromechanical texturing, Micro grinding, Micro casting and chemical etching were used commonly. Among these, laser surface texturing (LST) offers promising features: extremely fast processing time, clean to the environment and excellent control of aspect-ratio of the micro-holes. By controlling the orientation of the laser beam, and tuning the characteristics of the spot it is possible to easily texture a wide range of material, with no need of vacuum. This technique allows covering samples by regular arrays of ablated dimples, with different size and shape (typically spherical or cylindrical) [5].

Laser surface texturing (LST) is a well-known surface engineering process applied to improve surface tribological properties by fabricating artificial topography on the surfaces of materials. The dimples and grooves are the most common geometric features used for laser textured tribo-surfaces. Figure 2.1 shows different laser textured patterns on specimens. These textured surfaces can act as lubricant reservoirs that can feed the lubricant directly into the contact zone of sliding surface under starved oil lubrication [6, 7]. Another critical function of the textured surfaces is trapping of wear particles. The elimination of wear particles from the interface reduces friction and wear in both lubricated and dry sliding. Furthermore, the textured surfaces can also promote occurrence of hydrodynamic lubrication conditions and increase load-carrying capacity. To date, laser surface texturing has been used in many fields to improve the tribological performances of interfaces, such as mechanical seals, piston ring, cutting tools, thrust bearing, and magnetic storage devices [8].

II. LITERATURE REVIEW

Surface texturing has witnessed a substantial progress over the past decades as it is seen as a viable option for surface engineering, resulting in significant improvements in load capacity, wear resistance and friction coefficient of tribo mechanical parts [6], thereby contributing to the development of sustainable manufacturing and surface functionalization of components. In recent years, surface texturing successfully used in many applications to improve the tribological properties of sliding surfaces, such as golf ball, engine cylinder, modern magnetic storage device, sliding bearing and mechanical seal, and slider and disc of hard disc driver [7]. 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 to know their effect on materials [8].

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Various techniques of surface texturing have been developed over the years including additive and subtractive methods such as abrasive machining, reactive ion etching, electron beam and electro discharge texturing [9-12]. In comparison to other subtractive material processing technologies, laser surface texturing (LST) has attracted considerable interest for over ~20 years due to its superior flexibility, selectivity, accuracy, efficiency and capability for producing tailor-made surfaces with varying wettability, adhesion and friction properties [13]. Lasers have a great potential to precisely modify the surface characteristics of biomaterials, especially in the case of polymers. These can effectively modify the implant surface from the macro- to the nanosized topography without direct contact (avoiding undesirable contamination); moreover, laser treatments are clean, and easily performed on different materials with different geometry [14-15]. In laser surface texturing technology, a pulsated laser beam is used to create patterned microstructures on surface by a material ablation process, which can improve anti-seizing ability by reserving lubricant, decreasing the contact area to reduce adhesion, and generating hydrodynamic pressure to improve additional lift [16].

Journal bearings are vitally important elements as rotor supports in most mechanical systems operating with high horsepower and high loads, such as steam turbines, centrifugal compressors, pumps and motors. The materials used for journal bearings are commonly white metals (tin-based or lead-based), aluminium based and copper-based alloys. [21-22].The materials usually contain lead. But, lead is an inherent toxicity that causes deleterious, acute and chronic effects on plants and animals, and cumulative toxic effects on human beings. These health and environmental issues, in particular, are important to bearing manufacturers and users [23-27]. Copper alloys are used for bearing because of their combination of moderate-to-high strength, corrosion resistance and self-lubrication properties [28]. The wear of these alloys depends on structure (grain size and phase composition) [29]. Three groups of these alloys are used for bearing and wear-resistant applications: leaded bronzes; phosphor bronzes; and manganese, aluminium, and silicon bronzes [30, 31]. The leaded bronze has high resistance to wear, high hardness, and moderately high strength. They are widely used in bearing applications because of its anti-seizure property. Zinc also is added to the leaded bronzes to improve the running characteristics of the alloy during castings. Tin bronzes are alloys of copper and tin [32-34].

Friction behaviour is influenced by several variables, such as geometry, lubricant rheology and chemistry, relative motion, applied forces, presence of third-bodies at the interface, temperature, stiffness and vibrations. In most practical applications, the primary interest in the study of friction is sustained by the fact that the reduction of friction is directly linked to energy savings [35]. When considering materials for use in a sliding component, it is often desirable to subject them to tribotests to determine their wear behaviour under conditions similar to those they will encounter in service [36]. A tribometer (tribotester) is the general name given to a machine or device used to perform tests and simulations of wear, friction and lubrication which are the subject of the study of tribology. Often tribometers are extremely specific in their function and are fabricated by manufacturers who desire to test and analyse the long-term performance of their products [37].

In the past years, a range of tribometers were built to evaluate friction and wear [38-41]. For example, Lin [39] developed a linear tribometer composed of stainless-steel microballs, silicon stator and slider. It was found that the rolling friction coefficient between microballs and slider ranged from 0.006 to 0.01 at motor speeds of 90 and 120 rpm and load of 0.4g. Olaru [40] introduced a rotary tribometer consisting of a driving disc, an inertial driven disc and three microballs which are rolling between the two discs. Various types of tribometers are used to assess friction and wear of contacting surfaces viz. pin on disc tribometer, four-ball tester and high frequency reciprocating tribometer [41-43]. The pin-on-disc tribometer is a laboratory apparatus for evaluating the friction and wear properties of different materials under different conditions of load, speed and temperature [44].

III. EXPERIMENTATION

The leaded bronze pin materials prepared by cutting rods of size 500 mm into size 30mm length and 10mm diameter in hexa cutting machine and machining done on lathe. The disc material prepared by cutting rods of 120 mm length and 80 mm diameter into size 5 mm thickness and 80 mm diameter in hexa-cutting machine and machining done on lathe shown in fig 1.

Fig 1: Pin and disk specimens

Based on literature survey, density of patterns and type of pattern selected for laser texturing. 10, 15 and 20% texture density of ellipse patterns are created in AutoCAD software. Different texture density were obtained by keeping area of ellipse same only the pitch is changed. These patterns information are transferred to scan master design software for laser texturing. Laser surface texturing [LST] of leaded bronze specimens done using OR MAG Fiber laser in Mysore. The 10, 15, and 20% density patterns of elliptical types are created on the specimens using Yb- YAG fiber (nanosecond) laser by scan master design software.Parameters for nano second laser texturing is shown in table 1

Table 1 Parameter of Nano second laser

Sl. No.	Specifications	Range
1	Scanning Speed (mm/s)	250
2	Power (w)	10
3	Modulation frequency (KHz)	20
4	No. of Passes	1
5	Line spacing (unidirectional hatching) (mm)	0.01

For microstructure study of pin samples before and after wear and friction test, the optical images of pin specimens are taken using LABEN optical microscope. 10, 15 and 20% density elliptical pattern pin specimen's images are taken. The images of pin specimens are taken at same magnification (200X) for all density patterns. The next step after optical images of textured samples is roughness test. Mitutoyo surface roughness tester is used to measure the roughness of specimens. From roughness test, roughness and depth of texture are measured. The roughness values and graph of depth profile are generated using Mitutoyo SJ- 210 software.

The friction and wear behavior of textured patterns and textured specimens are analysed using Tribometer (pin on disc). Pin fixed in pin holder and disc is rotated at varying speed for particular period of time based on experimental design. Friction force and wear rate data points were obtained from the system which was attached to tribometer. Based on these data points coefficient of friction and wear rate graphs are plotted against the time.At first the pin which is subjected to friction and wear test is fixed inside the holder. Next step is fixing the pin holder to the pin on disc setup. After fixing the pin holder, required load is applied to the hanger and disc is fixed on the flat plate. Then friction and wear reading are set to zero and experimented is conducted for varying speed condition. The friction force and wear data points are obtained from the system.The 12 experiment conducted for three different disc sliding speed (rpm) 300, 350, 400, Sliding distance is 500 meter, wear track diameter is 23 mm. Load kept constant 1 kg. Next step is friction and wear test conducted on specimens at varying load condition keeping sliding speed constant. 12 experiment conducted for three different loads (kg) 1, 2, and 3. Sliding distance is 500 meter, wear track diameter is 23 mm and sliding speed kept constant at 450 rpm for all experiments.

IV. RESULTS AND DISCUSSION

The depth profile were obtained from the Mitutoyo surface roughness software which was attached to surface roughness testing setup. Four depth points on profile depth are chosen for measurement which are marked as 1 to 4 number in profile.The average of four texture depth is taken which is observed around 12.5 µm. Fig 2 shows depth profile 10% density textured specimen

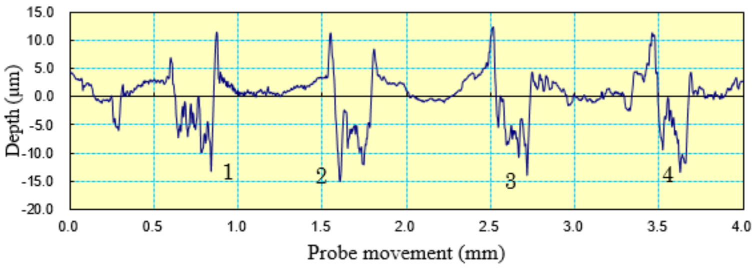

Fig 2: Depth profile of 10% density textured specimen

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The coefficient of friction of 10% density textured specimens at 300, 350 and 400 rpm are 0.32, 0.30 and 0.27 respectively. It can be observed that as the speed increases the coefficient of friction decreases. This is because of the reason that as speed increases point of contact decreases hence cof deceases. The relationship between varying load condition and friction coefficient for 10% texture density specimens against AISI 1045 disc at sliding speed of 450 rpm is shown in Fig 3. The coefficient of friction of 10% density textured specimens at 1, 2 and 3 kg are 0.26, 0.30 and 0.37 respectively. The lowest cof was found at 1 kg load condition i.e. 0.26. It can be observed that as load increases the cof also increases. This is because as load increases the point of contact between the pin and disc during friction test increase and hence cof increases.

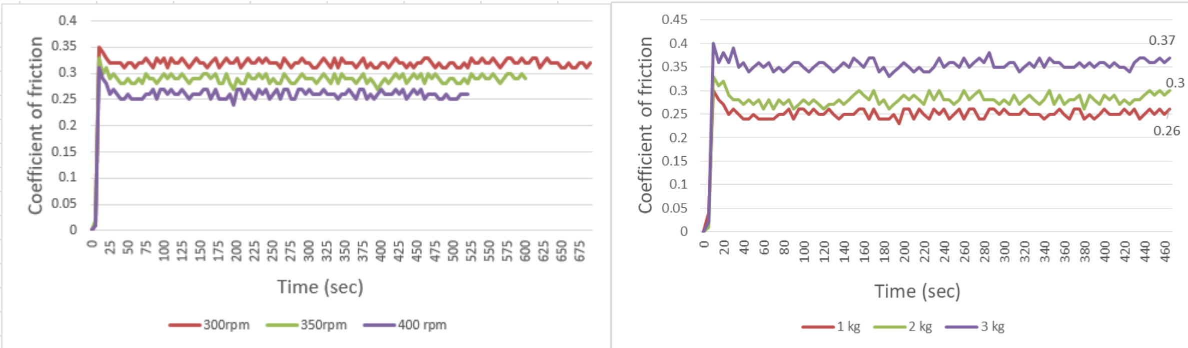


Fig 3: Cof graph at varying sliding speed and varying load

The lowest coefficient of friction obtained for 20% density at 400 rpm with 1 kg load i.e. 0.18. The highest coefficient of friction obtained for untextured specimen at 300 rpm with 1 kg load. It is evident that untextured specimen has more friction coefficient than textured specimen. Another observation is that as speed increases cof decreases shown in Fig 4.

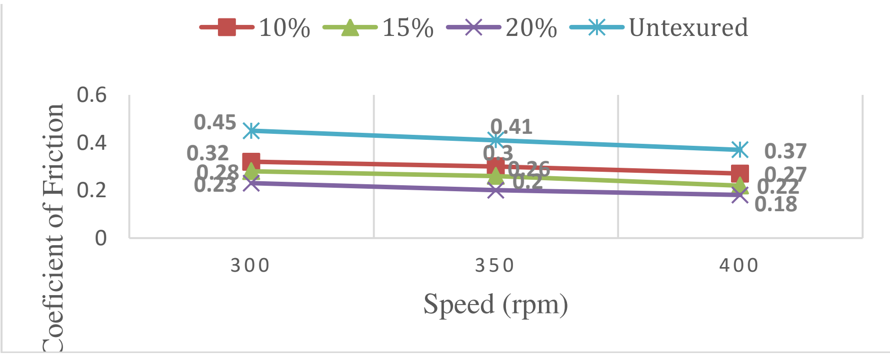


Fig 4: Cof graph for different specimens at varying speed condition

Specific wear rate of LST specimens and -untextured specimen with increasing load at constant sliding speed of 450 rpm is showed in Fig 5. The lowest specific wear rate obtained for 20% density at 1 kg with 450 rpm i.e. 2.45E-05 mm3/Nm. The highest specific wear rate obtained for untextured specimen at 3 kg load with 450 rpm i.e. 12.8E-05 mm3/Nm. It is evident that untextured specimen has more specific wear rate than textured specimen. Another observation is that as load increases specific wear rate increases.

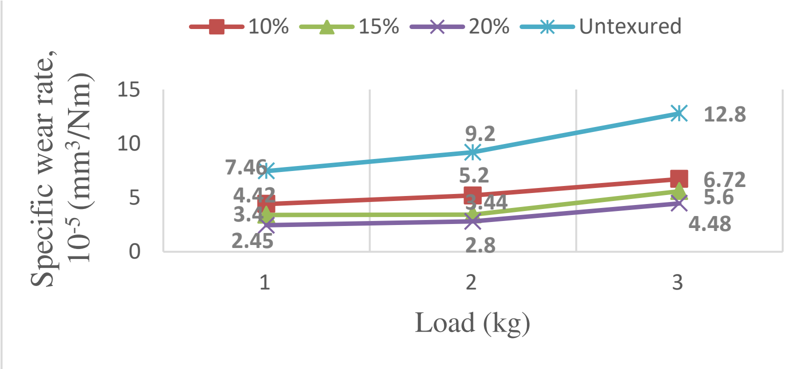
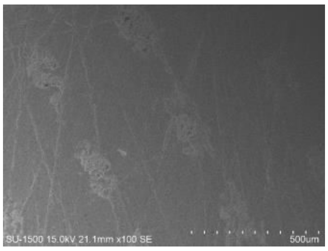
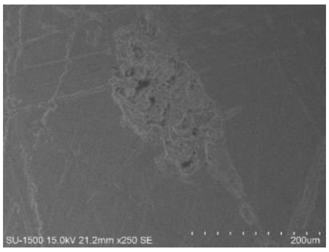
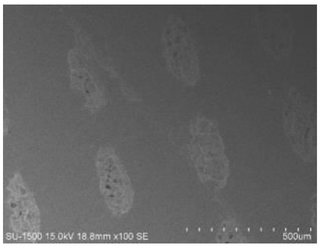


Fig 5: Specific wear rate at varying load conditions

The SEM images of worn specimen 20% texture density at maximum cof and wear rate are shown in the Fig 6. The minimum cof i.e. 0.17 of 10% density specimen at maximum load 1 kg at 450 rpm was obtained. The minimum wear rate i.e. 3 µm of 20% density specimen at maximum sliding speed 400 rpm at 1 kg load condition was obtained.







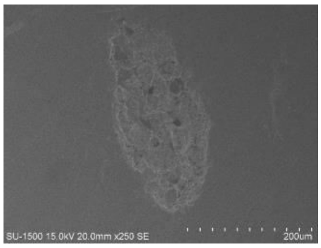


Fig 6: SEM micrograph of minimum COF and wear rate of 20% density specimens for load change &sliding speed

V. CONCLUSION

Laser surface texturing with elliptical dimples with major diameter 300 µm and minor diameter 150 µm, depth of 12.5 µm and texture density of 10%, 15% and 20% was applied to SAE 660 surface in order to investigate its effect on friction and wear reduction. Tribological tests were carried out against carbon steel AISI 1045 disc using pin-on–disc tester. Results indicated that laser textured surface had lower and more stable friction coefficient than untextured surface. The pin specimens with a density distribution of about 20% were more effective for friction and wear reduction under test conditions. During friction test at constant load condition the lowest friction coefficient 0.18 obtained for 20% texture density at 400 rpm at 1 kg load. Here as sliding speed of disc increases the friction coefficient of pin decreases. During wear test at constant load condition, as sliding speed of disc increases the wear rate of pin decreases. The lowest wear rate 4.8 E-05 mm3/Nm obtained for 20% texture density at 400 rpm at 1 kg load. From microstructure study, it was observed that for 20% texture density specimen smooth sliding marks were formed by contact. It can be seen that wear debris were trapped inside dimples which decreased the friction coefficient of the sample.

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