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Shifted laser surface texturing for bearings applications

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Abstract. The laser surface texturing (LST) technologies, based on creation of micro-pattern with pre-defined geometry can positively influence both the friction and wear of tribo-elements. In practice, the integration of LST technology is often limited due to its slowness. The new method, so called shifted laser surface texturing (sLST) with increased process speed was developed to make the technology more attractive for the industrial application. In the paper, the texture created by sLST technology was applied onto the steel samples and Al-Sn-Si surface of sliding bearings. Both block-on-ring (ASTM G-77) laboratory tests of steel samples and high-loaded working application tests on Al-Sn-Si bearings surface were carried out to evaluate the influence of texture on tribological behaviour. The ASTM G-77 laboratory tests showed a positive effect of the texture on friction behaviour. Under the high-loaded testing conditions, the positive effect was observed in initial stages of the tests, decreasing the torque of textured bearings compared to the untreated one. Lately, the texture was worn out and have no influence on the overall wear of the bearings. Based on the above mentioned observations, the use of alternative bearing material with higher hardness or application of protective layer over the created texture was suggested to exploit the texture benefits.

1. Introduction

In recent years, the utilization of lasers as a tools for surface modification became popular. Apart from the most widespread technologies, such as laser hardening or cladding for wear-resistant applications, a more sophisticated surface treatment can be applied to modify the surface properties.

The laser surface texturing (LST)is a technology of creation of pattern with defined geometry on the surface of treated parts. Depending on the shape of the texture, the surface can receive a new functional properties, such as hydrophobicity [1, 2], adhesion of subsequent layers [3,4], light absorption [5,6], self-cleaning [5] or tribological performance [7].

The principle of LST can be described as a removing of material by ablation process. Using the scanning optical systems for movement of the laser beam on the workpiece on predefined trajectories, the desired texture geometry can be created [8]. Although, the LST is a promising technology increasingly used in industrial applications, there are some limitations of current LST methods, such as heat accumulation and oxidation [9-11], plasma shielding effect [12] or precision at high speed [13]. To overcome the limitations the new method, called shifted laser surface texturing (sLST) was developed, enables effective use of existing state-of-the-art high power ultrashort pulse lasers. This surface texturing process, which utilises the average power and repetition rate of the ultrashort pulsed laser source more effectively than current methods via spreading the pulses temporally across the component to be textured, enables precise laser surface texturing to be performed, at industrially relevant speeds, whilst ensuring minimal thermal degradation of the component's surface. In detail, the sLST is described in [14,15].

The tribological performance is the matter of interest of many industrial applications such as bearings [16], shafts, piston rings [17] etc. Many studies exist concerning the influence of surface texturing on the sliding performance. They are addressing the influence of texture geometry on the shape of the sliding behavior experimentally [18] [19] [20], or using numerical models [21].

From the published work, the factors playing significant role can be identified, such as the density of textured area or the diameter to depth ratio of created dimples [22] [23]. Besides them, the quality of the texture, namely the amount of re-deposited material inside [24] or around [25] the created objects, is crucial for success in effort to decrease the friction and wear.

Based on the above mentioned studies, the texture design with potential to decrease the friction in the boundary/mixed lubrication mode was chosen and applied on the surface of bearings steel samples and Al-Sn-Si bearings. The laboratory ASTM G-77 test as well as the high loaded test simulating the bearings working conditions were performed to verify the positive effect of the created texture on the sliding behavior.

2. Experimental

The texture design (Fig. 1) was chosen based on the literature review and the results of preliminary study of sliding properties [26]. The diameter of the dimples was set 78 µm, the depth varied between 6.5-7 µm. The distance between the dimples centers was 200 µm, leading to the texture area density of 12%.

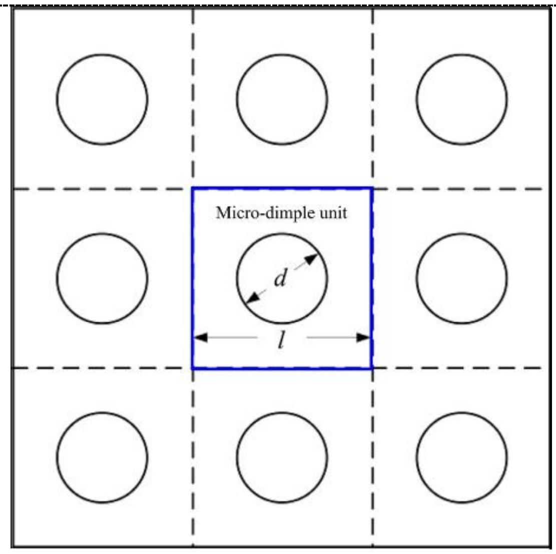

Figure 1. Texture design

The texture was applied on the outer surface of Timken A4138 rings, 35 mm outer diameter, made from the bearing steel (Fig. 2), and on the inner surface of Al-Sn-Si half bearings with inner diameter of 56 mm (Fig. 3).

The geometrical preciseness of the textured surface was evaluated by optical profilometer Bruker Contour GT X8.

Figure 2. Textured Timken A4138 ring

Figure 3. Textured half bearing

2.1. Texturing procedure

The Picosecond slab laser EdgeWave PX25-2-G with wavelength 532 nm, average power 14 W, pulse duration 10 ps and maximum pulse energy 100 µJ was used for texturing. The laser was equipped with scanning head with f-theta objective. The objective focal length was 255 mm, the laser spot diameter was 28 µm. Laser beam movement is produced by Scanlab software in connection with scanhead intelliSCAN® III 14. Maximal speed of laser moving is 8 m/s.

The sLST process of rings and bearings texturing was divided into several rectangular areas composed of array of dimples. Every textured rectangle was formed by sequential repetition of laser scanning processing of linear raster of individual spots – one spot per dimple in one repetition (Fig. 4). Between each repetition, the raster is slightly shifted to place next laser pulse with certain overlap. Individual spots are collected in four rings for every dimple. Whole quantity of the spots in one dimple is 127 laser pulses. Frequency of the laser pulses generation was 10 kHz, pulse energy 30 µJ and laser beam movement 2 m/s. Full process of forming of one textured rectangle contains 127 rasters (equal to the laser spots for one dimple) multiplied by 6 repetitions. After full finishing one of the textured rectangle the bearing was rotated to the next non-textured surface area for providing the next sLST processing. Rotations of the bearings were provided with step equal to the textured rectangular width 2 – 4 mm, depending on the bearing geometry. Speed of one movement between neighbor rectangles was set 50 degree per second.

Correct connection of the first and last textured rectangles was controlled by optical microscopy on Hirox 3D microscope. Total quantity of rectangles for full textured surface on ring with diameter 3.5 cm was 77 movements.

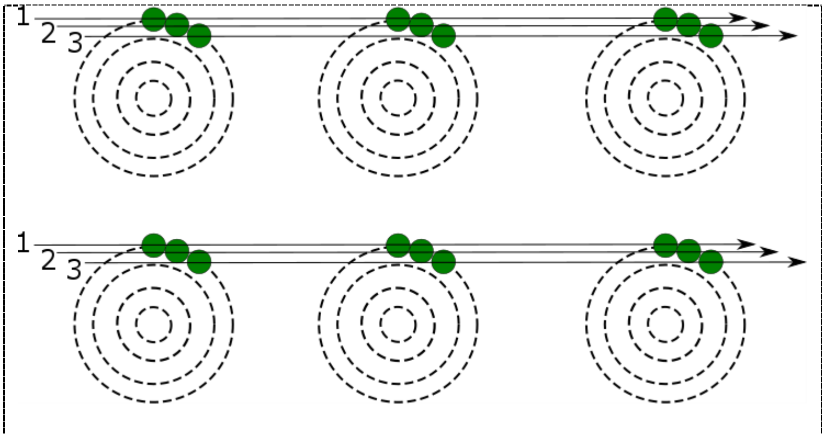

Figure 4. Schematic image of shifted Laser Surface Texturing (sLST)

2.2. *Laboratory Block-on-Ring testing*

The RTEC (RTEC Instruments, USA) universal tribometer was used to compare the sliding behavior of textured and non-textured Timken A4138 rings samples. The Block-on-Ring test, according to ASTM G-77 was carried out on non-textured sample (twice) and 3 samples with texture. The testing parameters are summarized in the Table1. Dip lubrication of the rings in mineral base oil was used and temperature of oil in the bath was recorded. All tests were started at similar temperature of the oil in the bath. During testing, the coefficient of friction (COF) was recorded. The surface topography was evaluated before and after the test.

Table 1. Testing parameters of “block-on-ring” testing

Item	Dimensions	Unit
Samples	Timken A4183, ø 35	mm
Counterparts	Block, 100Cr6, Ra 0.4	µm
Load	40	N
Speed (RPM)	10,20,50,100,200,400,700,1000,1500	min^{-1}
Intervals for each speed	10 (6 for 1000 and 1500 min^{-1})	s
Temperature	25 ± 2	°C
Lubricant	Mineral oil R834/90 (dyn. viscosity 0.115 Pas)	
Repetition	3 times from low seed to highest and vice versa	

2.3. *Harsh condition testing*

The testing system, developed in Daido Metal CO., Ltd. –The European Technical Center, was used to evaluate the behavior of Al-Sn-Si textured half bearings. The system is composed of a driving part where the shaft rotation can achieve up to 10 000 rpm, with loading and lubrication systems. For overloading conditions, the clutch is integrated. The loading system is applied by a hydraulic system able to simulate static and dynamic testing with force amplitude 100 KN and frequency 60 Hz. Bearings were tested for their wear resistance and ant seizure properties.

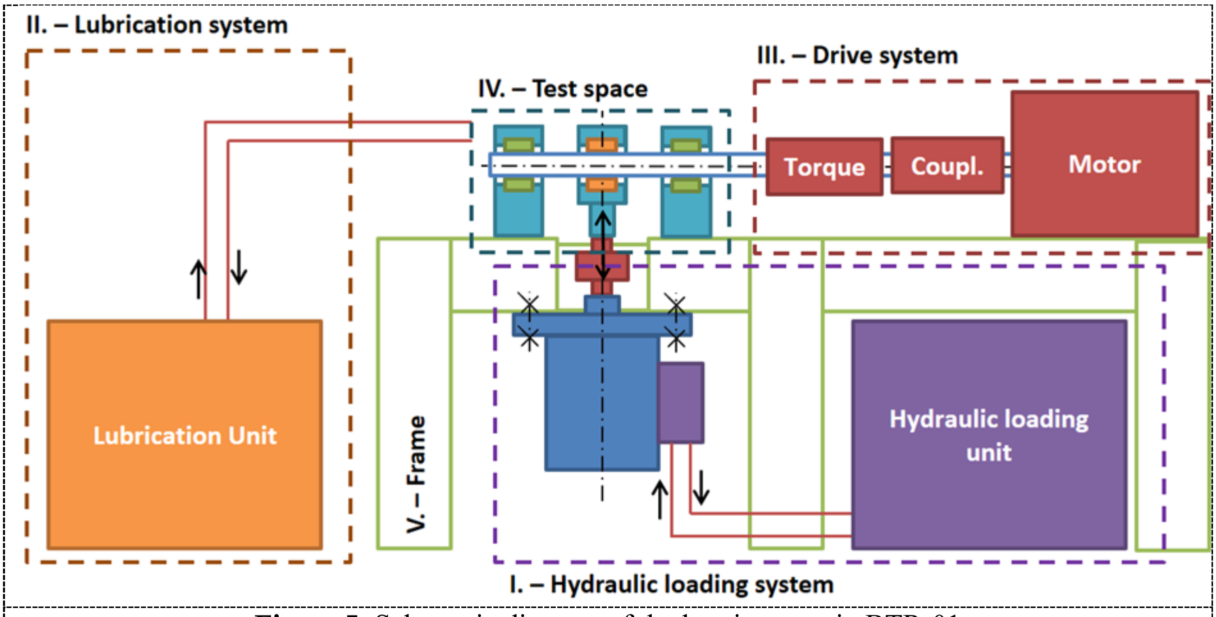

Figure 5. Schematic diagram of the bearing test rig BTR-01

2.3.1. Wear Test. Wear test conditions are described below in Table 2. The test machine was set for repeated start/stop cycling conditions for rotation of shaft to 1 m/s similar to hybrid vehicle or start-stop engines to be reproduced, i.e. with frequent start-ups when the oil film is sparse to promote bearing wear. The test mode is shown in Figure 6. Constant static load was set to the specific load (or nominal pressure) 5 MPa with limited oil flow supply of lubricant at room temperature. The wear volume was calculated from the measuring of the weight and the dimensional checks.

Table 2. Testing parameters of wear test

Item	Dimensions	Unit
Samples	Al-Sn-Si, ø 35W15xT1.5	mm
Counterparts	Shaft, Carbon steel, Rz ≤ 0.1	µm
Test specific load	5	MPa
Sliding speed	1	m/s
Test duration	20	hour
Lubricant	VG05	
Oil inlet temperature	Room temperature	
Oil flow	2.0	ml/min
Test mode	Start-stop	

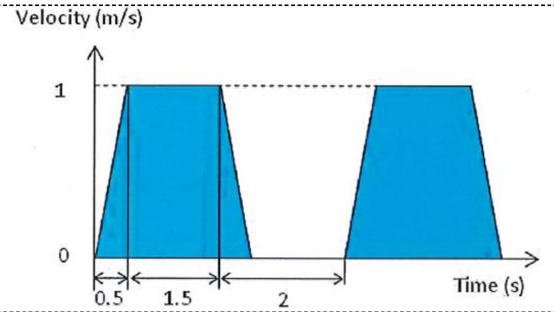

Figure 6. Schematic diagram showing the wear test mode

3. Results and discussion

3.1. Laboratory Block-on-Ring testing

The results of the Block-on-Ring testing summarized in the Figure 7. The average value of coefficient of friction and standard deviation is calculated from 6 measured values (each test was performed 3 times, the rotational speed was changed up and down).

From the measured results it can be seen, that the two rings (Textured 1 and Textured 2) showed lower friction in the area of lower speeds (up to 1000 min^{-1}). For higher speeds, the textured surfaces has the tendency to increase the friction compare to non-textured surface. According to the shape of the Stribeck curve and measured values, it can be said that the textured surface improves the friction in the mixed lubrication mode.

The results of Textured 2 sample showed opposite manner, but it has to be mentioned, that the behavior of the Textured 2 samples was not standard at all. According to optical profilometers

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measurements it can be estimated, that the sample differ from the others namely in the cylindricity of the basic geometry.

The same data are replotted against lubrication parameter in Fig. 8. Lubrication parameter is a ratio of lubrication layer thickness and the composite surface roughness. For the given testing configuration and materials, using the Hertz contact theory, film thickness prediction formula [27] and composite roughness (Rq 0.45 µm for the block; Rq 0.3 µm for the ring), the lowest measured COF was reached at the lubrication parameter in the range 3.5-4. It is known, that to full separation of the surfaces the value of lubrication parameter higher than 3 is needed [28].

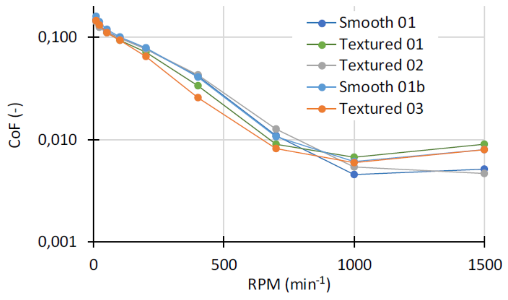

Figure 7. Comparison of COF for all measured Timken A4183 samples in dependence on the rotation speed

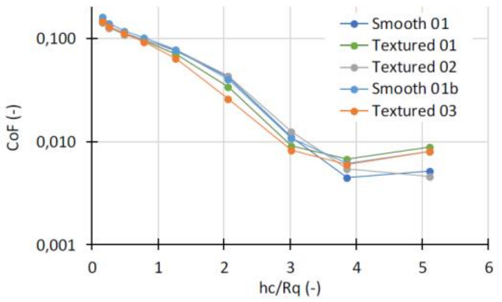

Figure 8. Comparison of COF for all measured Timken A4183 samples in dependence on the lubrication parameter

Discussing the choice of testing approach, it has to be mentioned, that the block-on-ring configuration, with line contact, is not the same as it is in the case of hydro-dynamically lubricated plain bearings. According to the Hertz theory, for the given testing configuration, the contact area is 72 µm wide. The value is smaller than the diameter of dimples in the texture (75-85 µm). Therefore, to improve performance of textures, a modification lead to wider contact area would be appreciated– e.g. use of a part of inner cylinder diameter as a counterpart geometry.

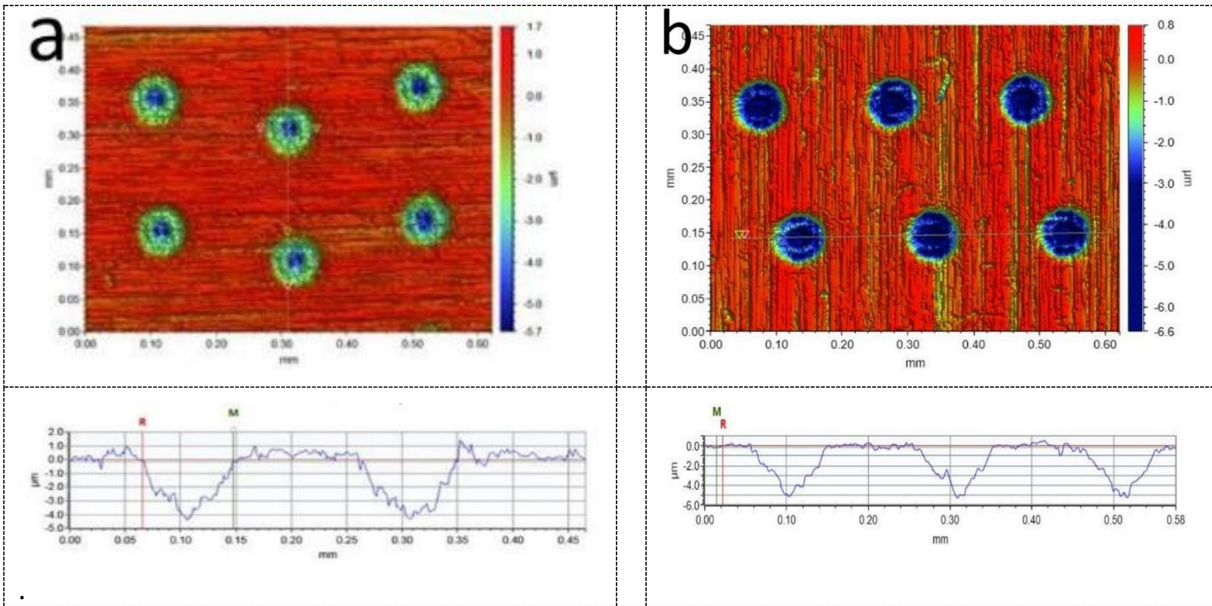

Figure 9. Surface topography before (a) and after (b) the wear test of the sample Textured 3

No wear of textured surfaces was recording during the block-on-ring tests. In the Figure 9, the comparison of the Textured 3 surface profile before (Fig. 9a) and after (Fig. 9b) test can be seen. Similar results were obtained also for the others samples.

3.2. *Harsh condition testing*

3.2.1. Wear test results. From the wear tests results (Fig. 10) it is obvious, that the texture was worn-out from the surface quite soon after the running of the tests, since the depth of textures varied between 6.5-7 μm. There is no significant difference in wear amount between the textured bearings and the untreated bearings.

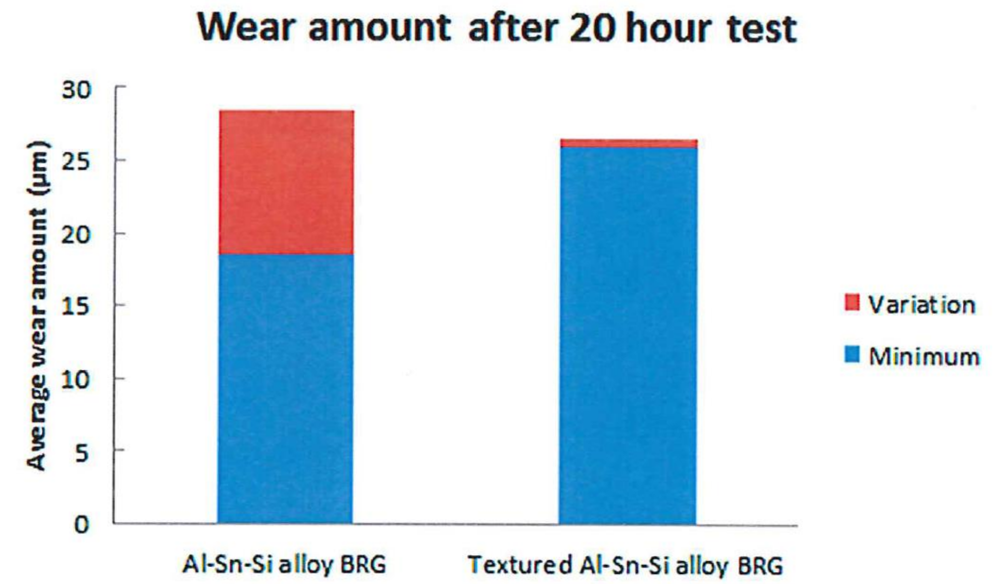

Figure 10. Wear amount after 20 hour wear test determined from the dimensional checks (two separate test bearings)

The wear occurs mostly around the main loaded area. The dimples in this area were completely removed after the wear test. The remaining textured surfaces were measured for surface topography to observe the evolution of the wear (Figure 11). The scans were carried out near the radial edge of the bearing, as there is less wear around that and the interface can be observed. Closer to the main area, no remaining texture was observed.

During the test, the torque on shaft was recorded. In the Figure 12, the comparison between the un-treated and textured bearings is shown in initial stage of stages of the test (Fig 12a) and after one hour of testing (Fig. 12b). While at the initial stages of the test the positive effect of the texture is obvious, just a little difference in torque between non-textured and textured bearings was found after one hour of testing due to worn out of the texture.

4. Conclusions

The efficient sLST method proves its suitability to produce the texture on the parts surface, which can positively influence the sliding behavior. The potential of the texture to decrease the friction in boundary lubrication mode was proved by both laboratory testing as well as by the testing under harsh conditions, where the torque of the shaft was decreased without the negative influence on the bearing wear. The lower measured torque in initial stages of star-stop test could be explained by faster oil formation during running. Although the positive effect of the texture was recorded namely in the initial stages of the test due to the fast worn-out, the very harsh condition of the test has to be taken into account.

Under real working conditions, the time to worn out of the texture is expected to be much longer. If the sLST method will be applied on more wear resistant bearing material that the Al-Sn-Si alloy, the lifetime of the textured surface can be also increased.

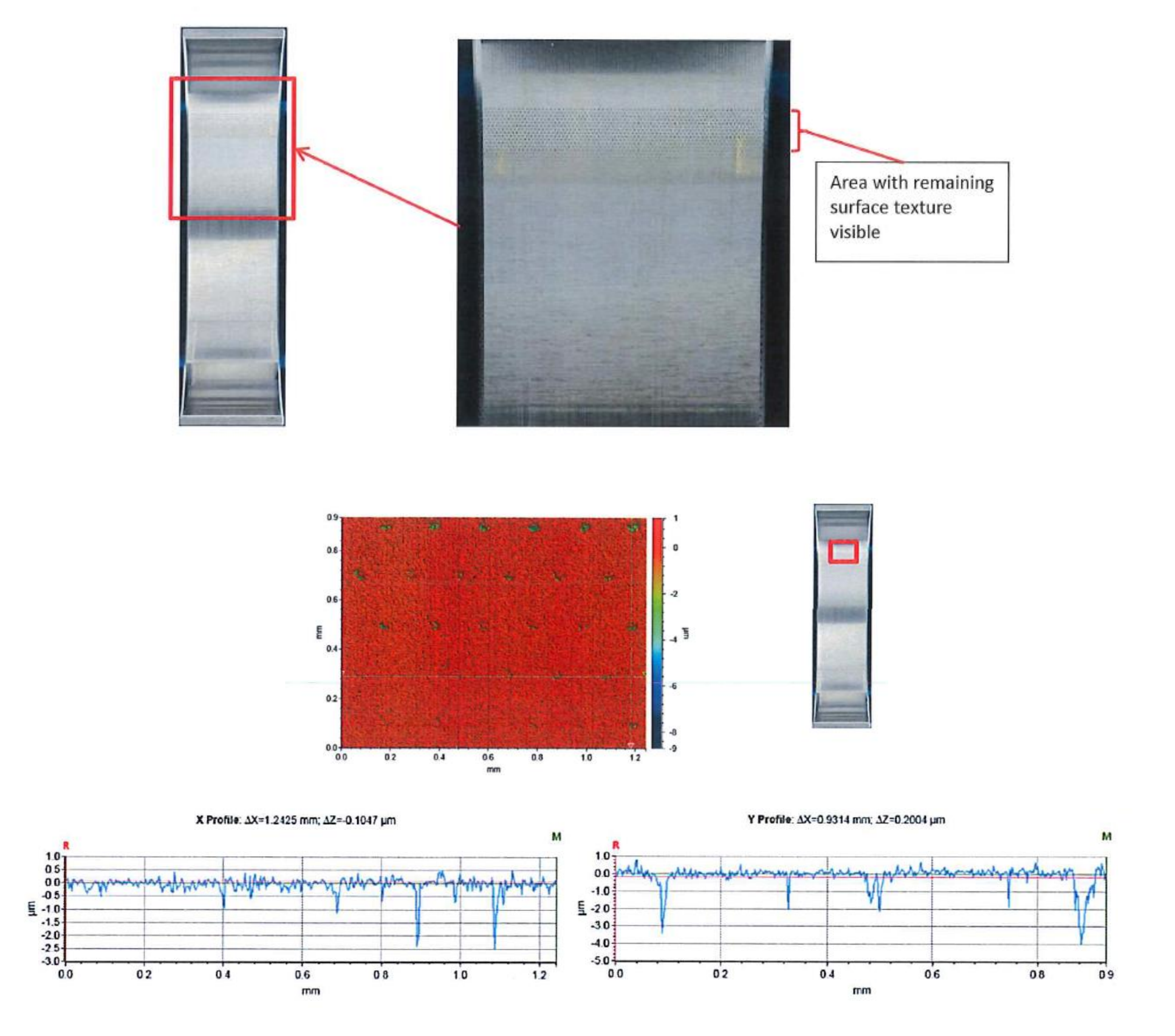

Figure 11. Dimpled area after the wear test

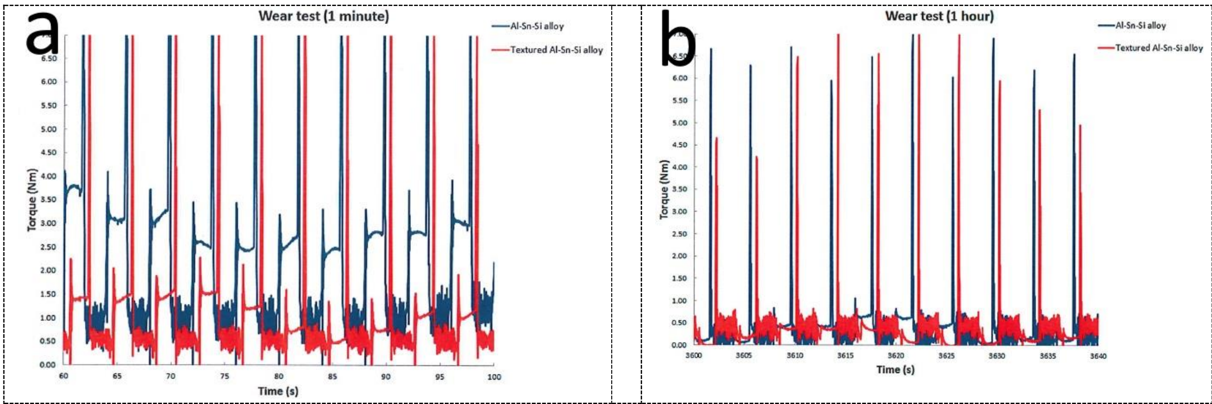

Figure 12. Torque measured during initial stage (a) and after 1 hour of testing (b)

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