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TRIBOLOGICAL CHARACTERIZATION OF CLOSED-SHAPED GEOMETRIES GENERATED WITH LASER SURFACE TEXTURING UNDER SLIDING CONDITIONS

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Abstract: Machining is one of the most common industrial techniques to produce components: it consists of removing material from a workpiece to a specific size or shape. One drawback of machining processes is that they tend to generate friction, heat and wear on cutting tools, which is usually associated with a low tool lifetime: this comes with high costs and low productivity, which in turn generates economic and ecological issues. One possible solution for these drawbacks is laser surface texturing (LST), a type of surface engineering technique which consists of creating micro or nano-cavities on the surface of the material to exposed to high-pressure contacts with the purpose of reducing friction and wear. LST parameters, such as geometry, density and depth, play an important role on tribological performance. This research focused on comparing and evaluating the coefficient of friction (COF) and wear of different closed-shaped textured geometries generated by LST, which included dimples or circles, hexagons and "benzene-shaped" figures. The purpose was to determine which of these three geometries presents best tribological performance under applied pressures. Tribological testing was performed with a T-05 block-on-ring tribotester under sliding conditions applying constant pressure (50 MPa) at 800 rpm and using a formulated commercial lubricant. Blocks of 1018 steel blocks were textured with the selected geometries. The results show that for under the selected testing conditions, hexagons and benzenes reduced COF by 20% and 34%, respectively, while hexagons had the lowest wear compared to untextured samples (70%). In future studies and applications, these results could potentially increase the lifetime of cutting tools employed for milling processes, which could reduce production costs and ecological impact.

Key words: Laser surface texturing, wear reduction, COF reduction, geometry, tribological characterization.

1. INTRODUCTION

Machining is one of the most commonly used techniques in the manufacturing industry to produce different types of pieces and components [1]. This process involves the removal of material from a workpiece to achieve the desired shape, size, and finish and is carried out using lathes, milling machines, drills, grinders, among others. All these processes lead to friction and wear on cutting tools, associated with high costs and low productivity [1]. Consequently, the use of tools in the industry poses economic and ecological problems [2–4], making it relevant to explore alternatives to increase tool life. One solution is through surface texturing [5], where material is selectively removed from the tool surface, creating nano or micro-cavities. In these cavities, debris and/or lubricant/cutting fluid are retained [6] and the textured surface finish can serve as an additional cutting edge for machining processes, which reduces friction and increases tool life [7]. Laser surface texturing (LST) is a technique that is efficient, high-quality, precise, easy to control, and relatively inexpensive [5]. This has been demonstrated in various studies, such as Schreck et al. [8], where it was shown that the coefficient of friction (COF) for laser-textured surfaces was reduced by 30% compared to polished steel and ceramic surfaces. Geometries to be applied can be categorised into two types: open and closed [7,9]. Open geometries are typically channels that allow the passage of lubricant, while closed geometries can be circles, squares, or any other closed shape. Maldonado et al. [10] textured blocks for block-on-ring tests with closed-type geometries such as circles, triangles, squares, and open-type geometries such as lines, crosshatch and S shape. Tribotesting was done under different contact pressures and results showed that under low pressures closed geometries had better performance, while under high pressures open geometries had the best tribo-characteristics. Regarding closed geometries, although circles are a common geometry in LST studies and applications [5,6], hexagons have recently proven to better retain lubricant [11–13] since they provide the most efficient way to pack the largest number of similar objects in a minimum space [11]. Furthermore, they have shown to provide cutting edges with their angles, or

inclined edges [14]. For example, Huang et al. [12] textured AISI 4140 steel samples with bionic or hexagonal shapes in combination with solid lubricants. Results showed a decrease of COF and wear height by 68% and 42%, respectively. In another study by Huang et al. [13] with similar bioinspired textured geometries, COF and wear depths were reduced by 24% and 42%, respectively.
In this research, three different geometries were textured using LST: circles, hexagons, and "benzenes" (hexagons enclosing smaller circles). Benzenes are proposed to determine the existence of a synergistic effect when applying geometries within others. On the other hand, circles have been found to improve tribological properties at low pressures (1.0 - 2.5 MPa). The aim of this study is to compare and evaluate the effects of different geometries on the COF and surface wear to propose the optimal geometry in manufacturing processes.

2. MATERIALS AND EXPERIMENTAL METHODS

2.1 Selection of LST geometries

First, a state-of-the-art study was conducted to identify the closed geometries with the best tribological performance in laboratory studies, as well as in manufacturing applications. It has been observed that the COF is favoured by circle geometries under a 5N load, with a 27% improvement in lubricant retention [15]. Additionally, a study by Zhong et al. [11] shows that edges in hexagonal figures can help retain lubricant better compared to rounded geometries. Adeyemi et al. [14] on the other hand, demonstrated that 75° angles in hexagonal patterns can serve as additional cutting edges. Therefore, the closed geometries selected for this study are circles, hexagons, and benzenes, considering the state-of-the-art studies (Fig. 1). It is expected to report lower wear and a lower COF compared to the non-textured base.

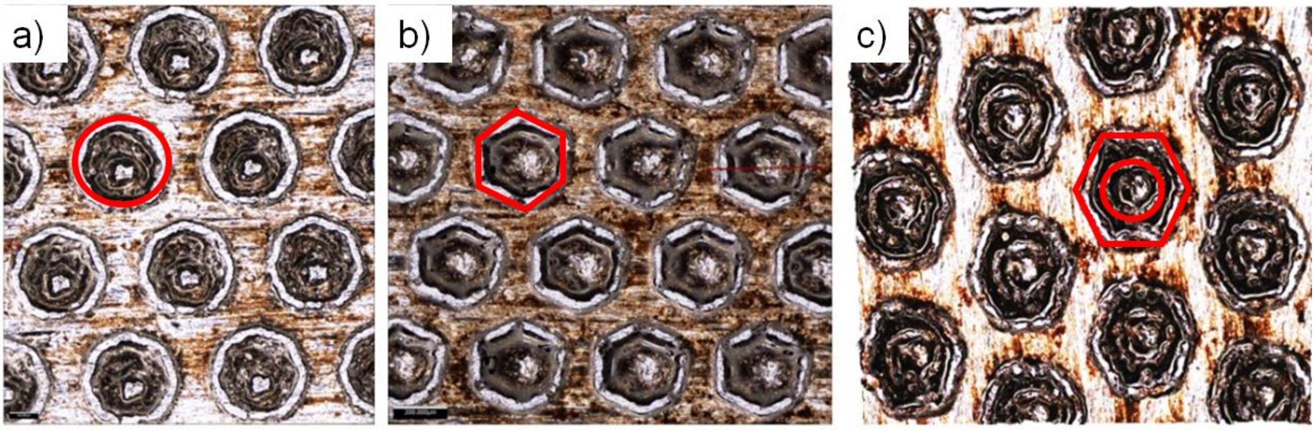


Fig. 1. Selected geometry patterns: a) circle, b) hexagon, c) benzene.

2.2 Texturing of samples

The selected geometries were modelled using EZCAD software for LST, and texturing was performed with an XM-20D laser, Dincel brand (Fig. 2a). When applying LST, various parameters, both geometric and technological, can be adjusted. Geometric parameters include all specifications of the pattern to be created: geometry, size, centre-to-centre distance, texturing density, or even depth. Several studies [10,16] show that COF and wear can be reduced by texturing closed geometries, making this type the focus of our study. Among the technological parameters are those directly controlled by the laser: the number of passes, speed, hatch lines, and power (%). For this project, technological parameters were kept constant for all factors and replicas to achieve depths ranging from 30 to 60 microns, considering previous studies with closed geometries [10,16]. With these parameters, the quality (hatch, speed) and depth (power and number of passes) of the texturing can be controlled. Regarding texturing density, since the current study focuses on closed geometries, textures with a density of 16% were selected, as this value has generally proven favourable for discrete shapes [6,10,17]. To achieve the desired depths in the geometries, an Alicona microscope (Fig. 2b) was used to monitor the laser results. Based on this information, texturing was repeated with different power levels and numbers of passes until the expected depths were obtained. After conducting various tests with different values, optimal parameters for laser texturing were determined, as shown in Table 1.

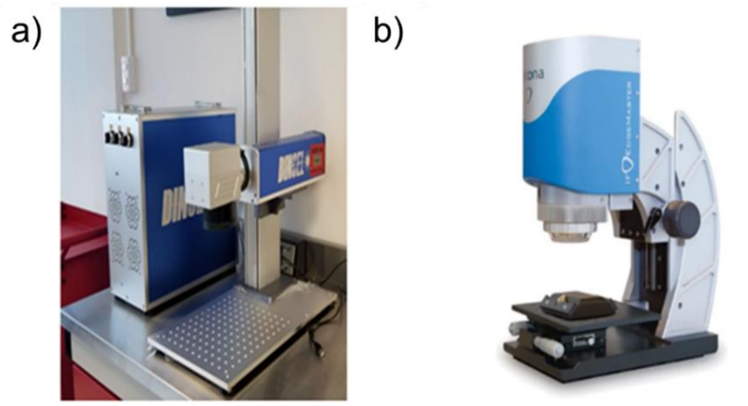


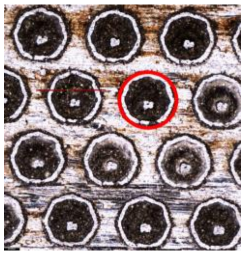
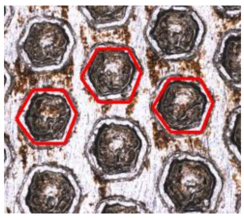
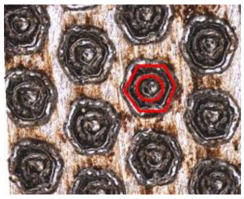
Fig. 2. Equipment utilised for the study, a) XM-20D laser model, b) Alicona microscope.

Table 1. Parameters used for LST of geometries.

Geometry	No. laser marks	Speed (mm/s)	Power (%)	Frequency (kHz)
Circle, Hexagon and Benzene	5	400	50	20

The dimensions of length, depth and area density of the geometries that were textured are shown in Table 2.

Table 2. Textured geometries and their dimensions.

Geometry	**Length (µm)**	**Depth (µm)**	**Density (%)**	**Image**
Circle	300	30-50	16	
Hexagon	300			
Benzene	300 | 150			

2.3 Tribological Characterization

Tribological tests were conducted using a T-05 block-on-ring tribotester (Fig. 3a). The materials used for the tribological tests were blocks of 1018 steel and D2 rings (Fig. 3b and Fig 3c). For all tests, the cutting fluid ECOCOOL AL 70 NK was used. The input parameters were a speed of 800 rpm, a load of 250 N, and a test duration of 2700 s. Using a load cell and a height sensor, the displacement of the test block and the friction force generated between the contact surfaces were obtained. Displacement serves as a measure of wear, and friction force, divided by the load, results in a COF value. Three repetitions were performed for the base configuration and each proposed pattern, resulting in a total of twelve runs. This test provided friction and displacement results. The friction, divided by the applied load, was used to calculate the resulting friction coefficients. On the other hand, displacement was used as an indicator of tribological wear.

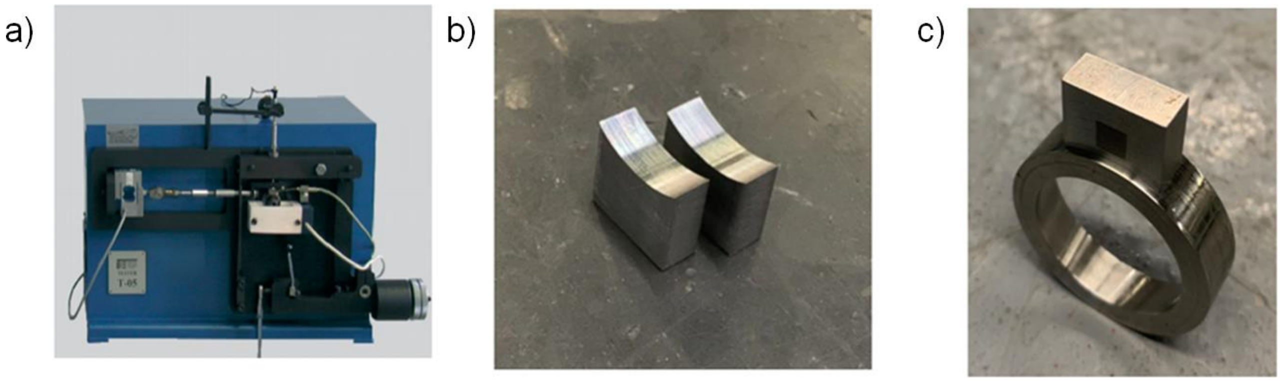


Fig. 3. a) T-05 block-on-ring tribotester, b) 1018 steel blocks, and c) tribo-pair of D2 ring and 1018 steel block.

3. RESULTS AND DISCUSSION

3.1 Coefficient of Friction

Fig. 4 shows the COF curves over the duration of the test for each of the sample conditions. It can be observed that laser texturing helped reduce the COF particularly with the geometries of hexagons and benzenes, whereas for circles, an increase was observed compared to non-textured pieces under the selected load. This increase in circles is attributed to applied higher pressures than in other studies found in the literature [18,19], suggesting that for higher pressure levels, it is advisable to texture circles with larger diameters and greater depth for better lubricant retention.

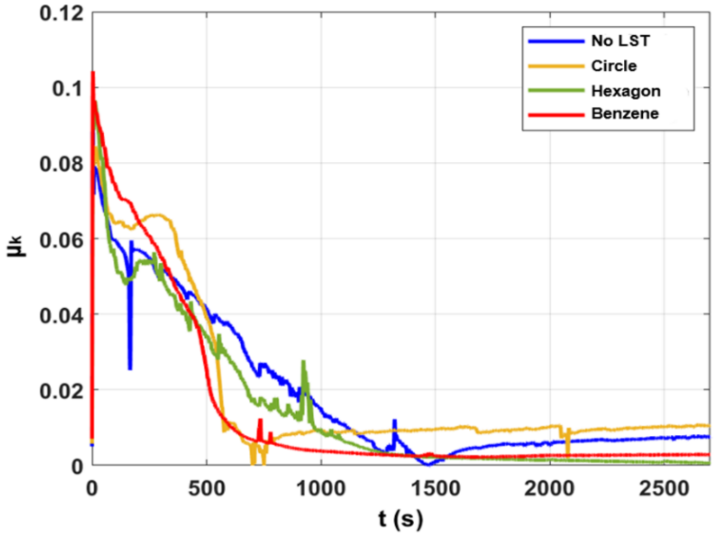


Fig. 4: COF curves vs time.

Average COF values in the steady state are shown for each textured geometry in Fig. 5. Similar to the results obtained in Fig. 4, the hexagonal pattern most contributed to COF reduction, followed by the benzenes. This is consistent with the results obtained by Adeyemi et al. [14] and Zhong et al. [11] that emphasize that the edges and angles (inclined sides) of hexagonal textures enhance tribological performance. The benzene shape showed a 34% reduction in COF, whereas hexagons provided a 20% reduction.

3.2 Wear results

Fig. 6 depicts representative wear displacement curves over time for each of the sample conditions. Hexagonal shaped structures provided the highest wear reduction compared to untextured samples, attributed to their shape that allowed for better lubricant retention, and the angles (inclined sides) acting as cutting edges. While the benzene shape first showed higher wear displacement compared to the untextured sample, the curve stabilized at about 500 s and the wear trend was much smaller, therefore at the end of the test the total wear displacement was reduced. For circles, higher wear values were obtained, consistent with the COF results obtained in Fig. 4 and 5.

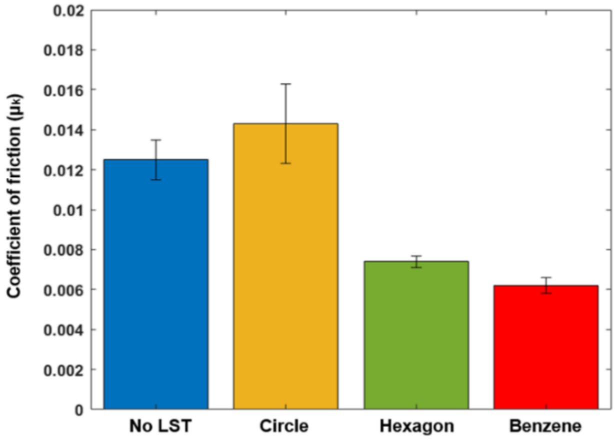


Fig. 5. Average COF vs LST pattern.

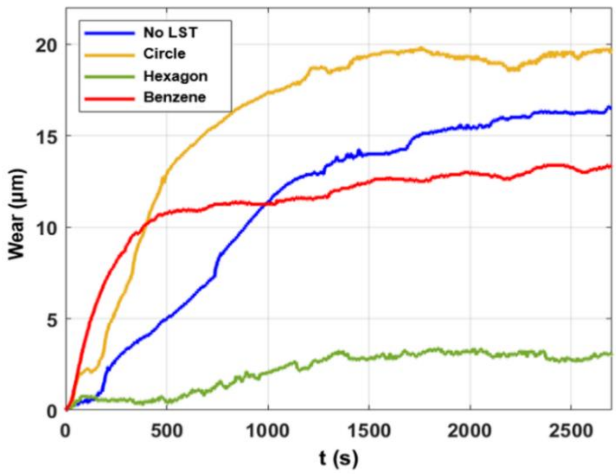


Fig. 6. Wear displacement of the tribosystem vs time.

Similarly, Fig. 7 depicts the average displacement values for each geometry at the end of the test. It can be observed that benzenes and hexagons reduced wear by 11% and 70%, respectively, while the circle increased wear. These results are comparable to the ones obtained by Adeyemi et al. [14] and Zhong et al. [11].

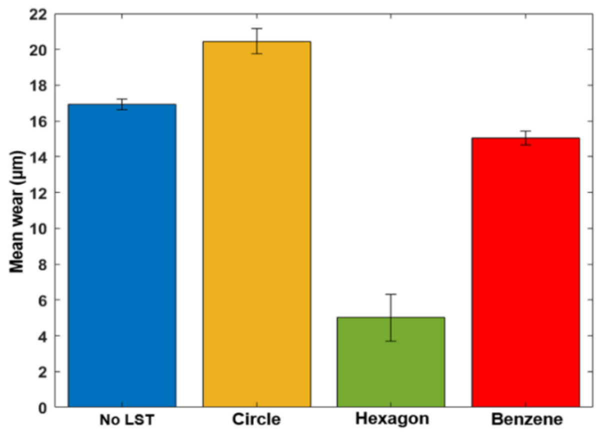


Fig. 7. Average Wear of the tribosystem vs LST pattern.

Fig. 8 present depths before and after subjecting the rings to the block-on-ring wear test at 50 MPa. Circles (Fig. 8a) exhibited the most significant wear, with a 10 μm depth reduction. Hexagons (Fig. 8b), with the least wear, showed a 5 μm reduction and benzenes had an 8 μm reduction (Fig. 8c), probably attributed to wear debris filling the circular cavity inside the hexagon.

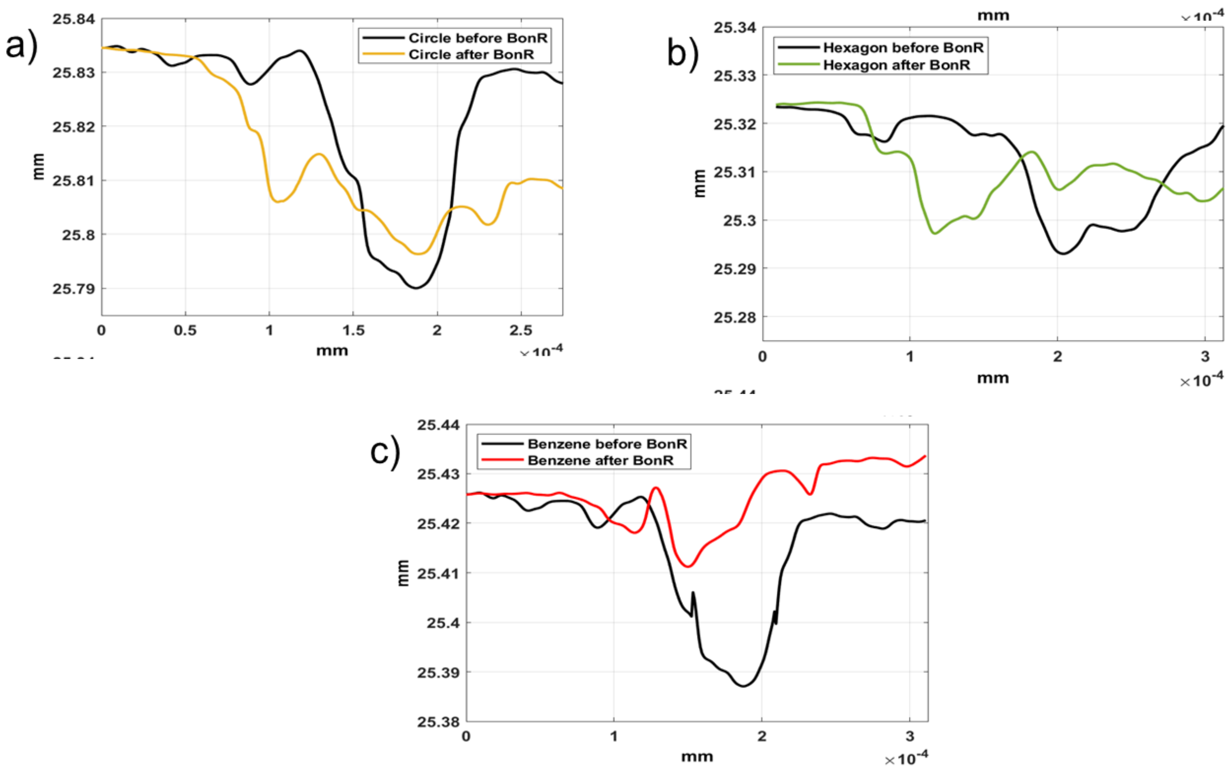


Fig. 8. Reduction in depth for: a) circles, b) hexagons and c) benzene geometries after wear testing at 50 MPa

4. CONCLUSIONS

Laser texturing has proven to be an economical and easy to apply technique that significantly increases the lifespan of tools used in various industrial processes. Among the different geometries evaluated in this study, the hexagon stood out for its excellent performance in laser texturing applications. This geometry reduced the COF by 20% and material wear by an impressive 70%. The hexagonal shape allowed better lubricant retention, while providing more cutting that enhanced both friction reduction and wear.
In contrast, the benzenes geometry showed good behaviour but did not reach the performance levels of the hexagon. Although it achieved a higher COF reduction at 34%, it only improved wear resistance by 11% compared to the non-textured piece. This is attributed to a lower depth of edges in the benzenes texture (due to the circle inside of the geometry), resulting in inferior performance in terms of friction and wear. As for the circle geometry, it exhibited worse performance than the non-textured piece. Both COF and wear increased by 14% and 21%, respectively. This is mainly because circles cannot optimally retain lubricant under high-pressure conditions, resulting in COF increases. For future research, a more in-depth study of hexagon behaviour is suggested, exploring its performance with different materials and other laser texturing parameters to assess its response to various depths and texturing qualities.
Additionally, futures studies should focus on applying the findings of this study in industrial processes, such as laser texturing of cutting tools, endmills, drill bits, among others, employed for machining processes.

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Conflicts of Interest: There is no conflict of interest.

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