

Tribological properties of plunging-type textured surfaces produced by modulation-assisted machining

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ABSTRACT

Surface texturing technology has started to gain attention in the tribology community as a method for improving friction and lubrication ability of various mechanical components. Micro-sized depressions (e.g., grooves or dimples) on frictional surfaces act as fluid reservoirs and promote the retention of a lubricating thin film between mating components. Several fabrication techniques can be used to produce micro-dimple patterns on surfaces, but most of them show limitations when employed in practical efforts. The use of modulation-assisted machining (MAM) processes provides a cost-effective approach for creating surface textures over large areas that offers high control over the characteristic geometry of the textured surface.

In this work, the effects of surface texturing and the influence of the dimensions of micro-sized depressions produced by MAM on wear performance are studied. Alloy 360 brass is mated with AISI 440C steel and studied using a ball-on-flat reciprocating configuration. Lubricated wear tests are carried out under conditions of variable frequency and normal load. The textured surfaces exhibited reduced wear under the highest frequency studied. The tribological performance of the surfaces is observed to depend on the size of the micro-dimples.

KEY WORDS: wear, textured surfaces, brass.

1.- INTRODUCTION

Every year, much of the energy that the world consumes is wasted through friction and wear in mechanical and electromechanical systems. Approximately 11 % of the total energy annually consumed in the U.S. in the four major areas of transportation, turbomachinery, power generation and industrial processes is lost due to friction [1]. Friction is considered to be responsible for major losses of useful mechanical energy and wear is a main reason for replacing equipment. A better understanding and utilization of the principles of tribology is particularly important for conservation of energy and materials in engineering design [2].

Surface texturing technology has started to gain attention in the tribology community as a method for improving friction and lubrication ability of various mechanical components [3]. Micro-sized depressions (e.g., grooves or dimples) on frictional surfaces act as fluid reservoirs and promote the retention of a lubricating thin film between mating components. The dimples or grooves also function as receptacles for debris and wear particles, eliminating potential scratching of the substrate surface during relative motion of the interface parts. In addition, the depressions boost the hydrodynamic pressure that causes separation of the surface. Several fabrication techniques can be used to produce micro-dimple patterns on surfaces, but most of them show limitations when employed in practical efforts [4, 5]. The use of modulation-assisted machining (MAM) processes provides a cost-effective approach

for creating surface textures over large areas that offers high control over the characteristic geometry of the textured surface. In this method, surface textures are controlled by the machining and modulation parameters. In conventional machining, the chip formation process occurs in a continuous manner and the tool is always in contact with the work. It is shown herein that machining with a controlled low-frequency modulation (<1000 Hz) effects discrete chip formation and disrupts the severity of the tool-chip contact in a controlled manner with attendant benefits [6, 7]. Furthermore, because of the additional degrees of freedom offered by the modulation, MAM can be used for surface texturing and for production of powder particulate.

In rotary turning, two basic configurations for realizing surface textures by MAM are possible. The first configuration is known as 'sliding type'. In this configuration, the superimposed modulation is applied in the direction of tool feed in turning (Figure 1a). In the second configuration, known as 'plunging type', the superimposed modulation is applied perpendicular to the tool feed (Figure 1b). It is important to note that, these two different texturing configurations can be applied on both inner and outer cylindrical faces, as well as on the flat surfaces of work cylinders depending on the specific configuration used.

In this work, the plunging-type texturing configuration (Figure 1c) was used to create textured surfaces. In this configuration, the tool is engaged in the axial direction with a constant depth of cut (d_c) and is fed in the radial direction at a feed rate (h_o). The modulation is applied in the axial (depth of cut) direction, which causes a periodical change in the depth of cut (d_c). Depending on the cutting and modulation conditions the surface finish could be altered, generating dimples of different geometry. In this paper, the effects of surface texturing and the influence of the density of micro-sized depressions produced by MAM on wear performance are studied under lubricated ball-on-flat reciprocating configuration.

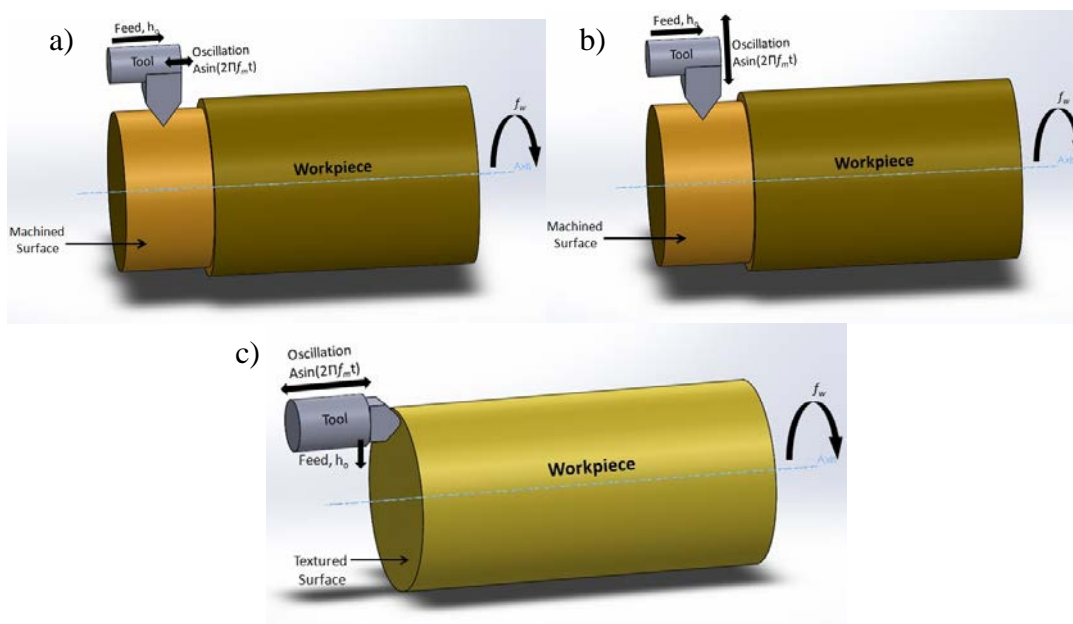


Figure 1. Configurations to produce textured surfaces on outer diameter of cylinders by (a) sliding-type texturing and (b) plunging-type texturing. (c) Configuration to produce textured surface on cylinder flat faces by plunging type texturing.

2.- EXPERIMENTAL DETAILS

360 brass disks with textured surfaces created by MAM were tested in a ball-on-flat reciprocating (Figure 2) tribometer against AISI 440C stainless steel balls (3 mm spherical radius, 690 hardness HV). The sliding time (20 min) and amplitude (10.5 mm) were kept constant for all tests. Variable frequency tests were carried out under constant normal load of 23N (corresponding to mean hertzian contact pressure= 0.91 GPa and maximum hertzian contact pressure= 1.37 GPa). Variable load test were carried out under a constant frequency= 1.5 Hz. 2 ml of a synthetic poly alpha-olefin oil (Synton PAO 40) were applied on the brass surfaces prior to each test and no additional lubricant was added during the test.

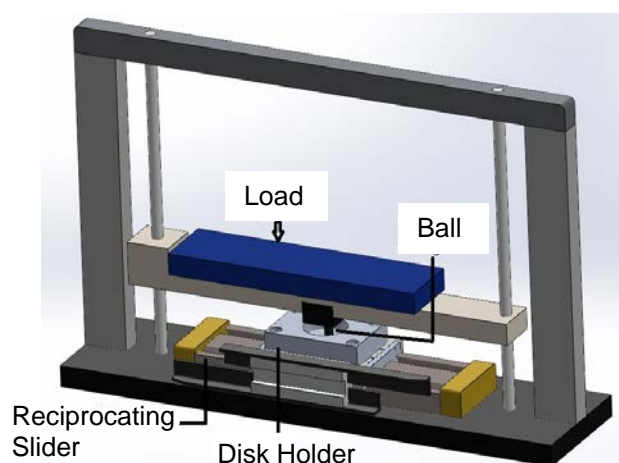


Figure 2. Ball-on-flat test configuration.

Textured surfaces were created by MAM using plunging-type texturing configuration with constant surface speed. Table 1 shows the machining and modulation conditions of the samples. In order to establish the effect of dimple density, three textured samples with different dimple densities, low, medium and high (LDD, MDD, HDD, respectively), were created by changing the modulation conditions (Table 1) of the manufacturing process. Figure 3 shows the optical images of the control sample and the three textured surfaces.

Table 1. Machining and modulation conditions for samples; where h_0 =feed rate; r_t = tool tip radius; A = modulation amplitude; f_m =modulation frequency.

Sample	Modulation Conditions		Machining conditions		
	F_m (Hz)	A (mm)	h_0 (mm/rev)	Speed	r_t (mm)
CS	Control Sample		0.01	1000RPM Spindle speed	2.5
LDD	100	0.03	1.5	0.91 m/min Surface speed	2.5
MDD	100	0.03	1	0.91 m/min Surface speed	2.5
HDD	100	0.03	0.5	0.91 m/min Surface speed	2.5

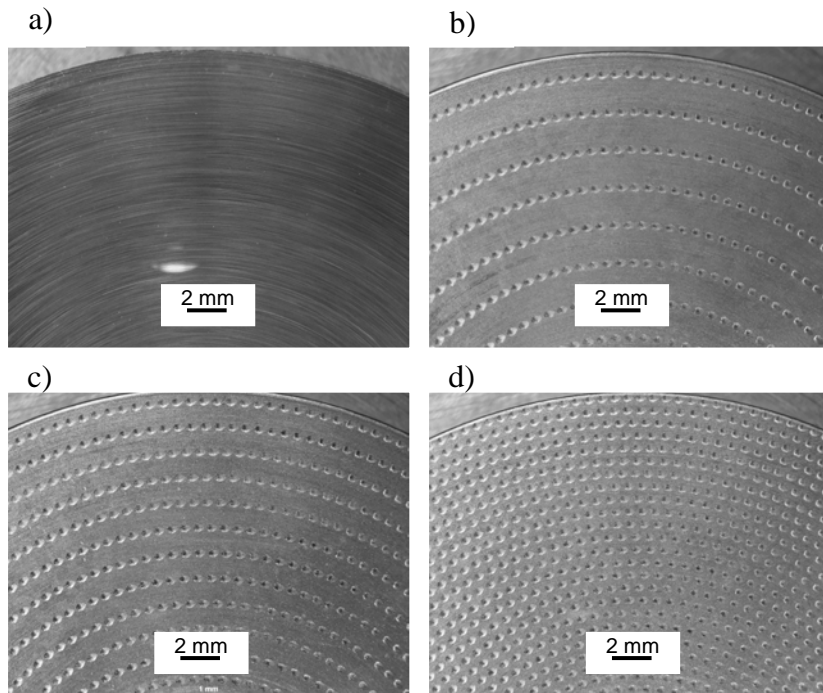


Figure 3. Optical images of the samples: (a) CS; (b) LDD; (c) MDD and (d) HDD.

Wear was obtained after three tests under the same condition. Volume loss was determined by image analysis after 45 wear track width (W) measurements (Figure 4) for each test, according to Eq. 1 [8]:

$$V_f = L_s \cdot \left[R_f^2 \arcsin\left(\frac{W}{2R_f}\right) - \left(\frac{W}{2}\right)(R_f - hf) \right] + \frac{\pi}{3}(3R_f - hf) \quad (1)$$

As can be seen in Figure 4, W is the wear width, L_s is stroke length and R_f is the radius of 440C steel ball.

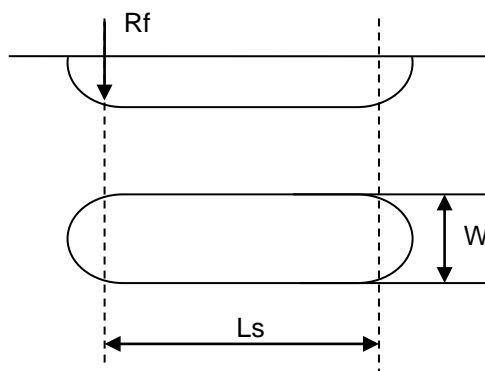


Figure 4. Schematic of a wear scar on a flat specimen against a spherical pin of radius R_f .

Optical micrographs were obtained using a Zeiss optical stereoscope.

3.- RESULTS AND DISCUSSION

3.1.- Effect of sliding frequency

For this section, the experimental analysis was carried out at constant load and time. Figure 5 compares wear volumes of the four samples obtained under increasing frequency. Under the lower frequency studied (1.5 Hz), no major differences were observed between textured and un-textured surfaces. As frequency increases, the dimples have an effect on surface wear performance, consistent with previous observations of their importance as fluid reservoirs and their ability to promote retention of a lubricating thin film at sliding interfaces [9, 10]. A maximum wear reduction of 50% compared with the control sample was obtained for the textured surface with medium dimple density (MDD).

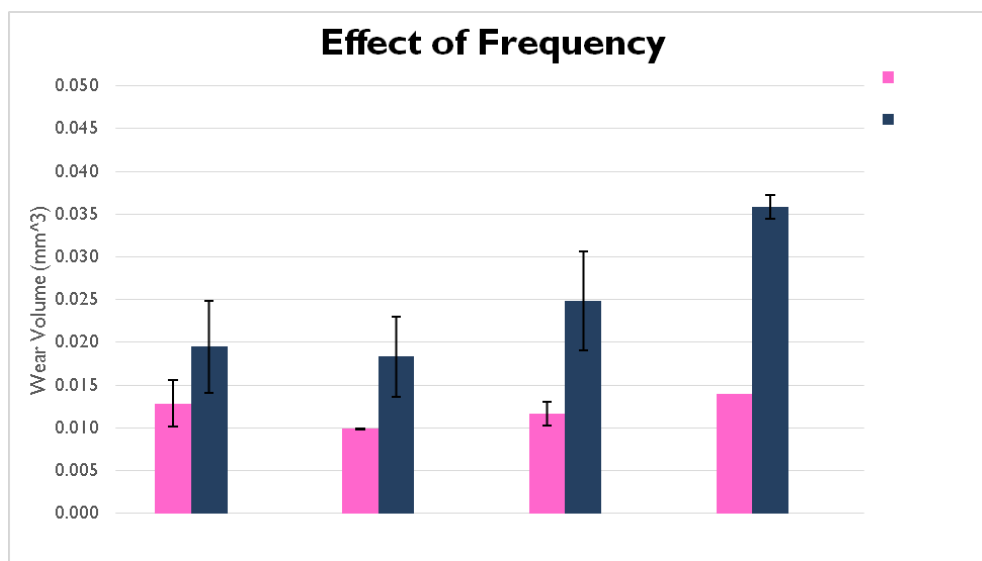


Figure 5. Average wear volume- Effect of frequency (sliding time= 20 min and normal load = 23N).

Figure 6 shows wear tracks for MDD and CS samples after the wear tests under the same set of experimental conditions. From the figure, while wear widths for both samples are pretty similar under 1.5 Hz, when the frequency is increased, a much wider wear track is obtained for the un-textured surface.

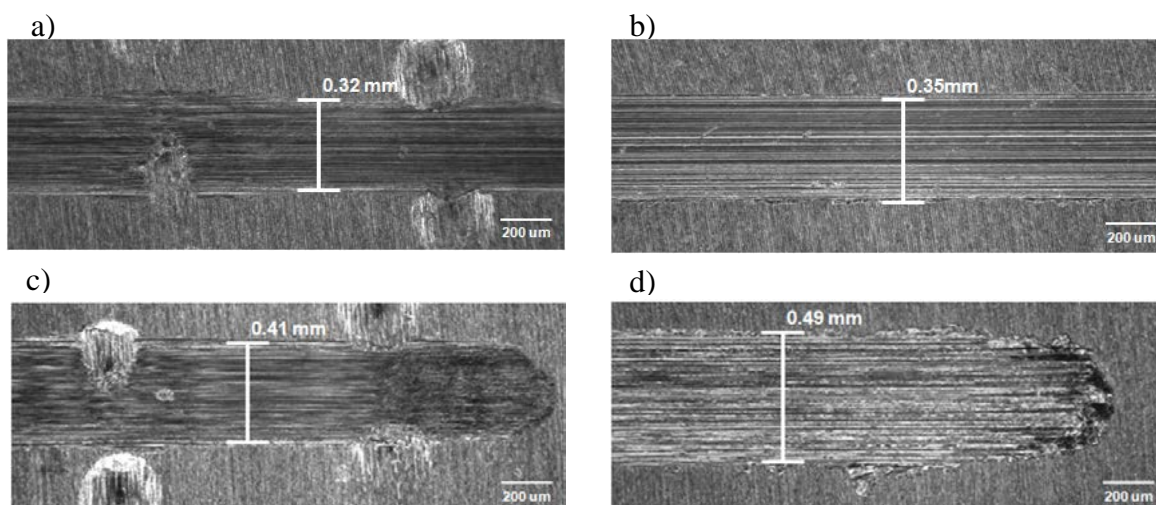


Figure 6. Wear track, showing the average value of wear width for each condition, on (a) MDD-23 N, 1.5 Hz; (b) CS- 23 N, 1.5 Hz; (c) MDD-23N, 3 Hz; (d) CS-23N, 3Hz.

3.2.- Effect of normal load

In order to study the effect of the normal load on the wear performance of the textured surfaces, sliding time and frequency of the experiment were kept constant. As can be seen in Figure 7, increasing the normal load increases the wear volume of the four surfaces. Under the lower normal load, wear volumes are very similar for all materials. Under the higher load studied, medium dimple density sample (MDD) is again the most wear resistant material, showing a wear volume reduction of 41 % with respect to the control sample. These results are in agreement with [11, 12]. Increasing the dimple density on the sample improves the wear performance until an optimum value is reached. Beyond this point, an increase of the dimple density increases the wear volume of the samples. This optimum value of the dimple density will depend on the geometry of the dimples and the experimental conditions studied.

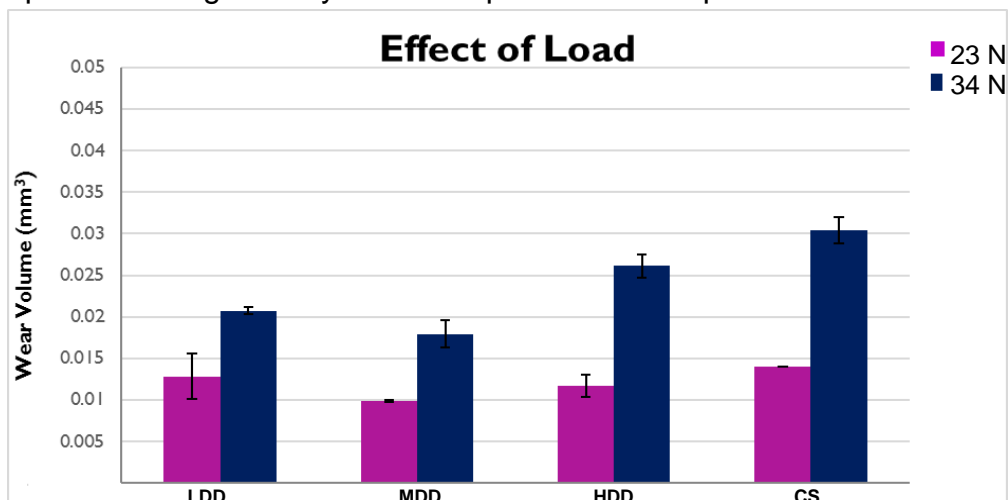


Figure 7. Average wear volume- Effect of normal load (sliding time= 20 min and frequency= 1.5 Hz).

3.2.- Wear mechanisms

In all cases, a strong component of abrasive wear was observed, as pointed out by the abrasion marks clearly parallel to the sliding directions in Figures 6 and 8. When the severity of the contact condition increases (higher load and higher frequency) a component of plastic deformation is also observed, particularly for CS, where lateral plastic flow creates accumulation of material at the edges of the wear track (Figures 6 (d) and 8 (b)).

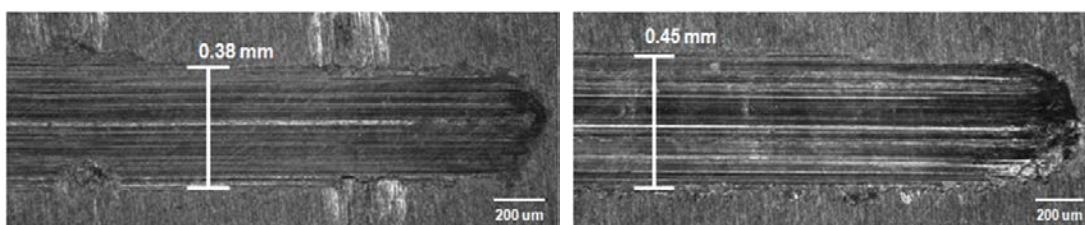


Figure 8. Wear track after a test under 34 N and 1.5 Hz, showing the average value of wear width for each condition, on (a) MDD; (b) CS.

AISI 440C steel balls presented no apparent wear loss, under the experimental conditions studied, but showed an adhered layer of brass wear particles (Figure 9).

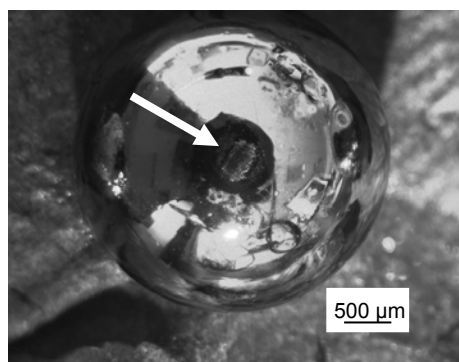


Figure 9. Optical micrograph of steel ball after a test against MDD (34N, 1.5 Hz). Arrow show adhered material.

4.- CONCLUSION

In this paper, the effects of surface texturing and the influence of the density of micro-sized depressions produced by MAM on wear performance are studied under lubricated ball-on-flat reciprocating configuration.

Under the experimental conditions studied, textured surfaces showed a better wear performance than un-textured surfaces, particularly under increasingly severe contact conditions such as high frequency and load.

The sample with medium dimple density (MDD) was the most wear resistant material, showing a wear volume reduction of more than 41% with respect to control sample under high load and high frequency. Increasing the dimple density on the sample improves the wear performance until an optimum value. After this value, an increase of the dimple density increases the wear volume of the samples. This optimum value of the dimple density will depend on the geometry of the dimples and the experimental conditions studied.

ACKNOWLEDGEMENTS

The authors acknowledge financial support from the FEAD grant program at the Rochester Institute of Technology and from NSF grants CMMI 1130852 and 1254818

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