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ENHANCING ENDMILL TOOL LIFE THROUGH LASER SURFACE TEXTURING IN BRASS MACHINING: A CASE STUDY

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Abstract: This study focused on the manufacturing of C-36000 brass workpieces at a local manufacturing company, highlighting a significant issue related to the premature wear of machining cutting tools. This wear led to frequent tool replacements and increased downtime, negatively impacting production efficiency. To address this challenge, laser texturing was applied to the endmills used in the brass machining process. The goal was to evaluate laser surface texturing (LST) as a solution to reduce tool wear, extend tool life, and optimize the overall manufacturing process. LST is a modification technique that creates microcavities on tool surfaces. This process has been shown to enhance tool performance in machining operations by improving lubricant retention, reducing friction, and minimizing wear. Additionally, the microcavities formed by LST can promote better lubricant flow, reduce operational temperatures, and ultimately increase the tool's durability and cutting efficiency. In this study, two laser texturing patterns—45°-channels and dimple arrays—were selected based on their potential to optimize lubricant flow and reduce frictional forces that contributed to tool wear. Tests were conducted using a CNC machining center to machine 1,000 brass workpieces. Wear mass loss measurements were taken for both untextured endmills and those with laser-textured surfaces. The results demonstrated that the endmills with 45°-channels experienced an 86% reduction in mass loss compared to the untextured endmills, while the dimple-patterned endmills showed higher mass loss, likely due to fracturing. This finding suggested that the angled channel design was more effective at retaining lubricant and reducing friction. Surface profile analysis further confirmed that the open geometry of the angled channels promoted better lubricant flow and provided additional cutting edges, which contributed to reduced wear. Additionally, these geometries resulted in less than 5 µm depth reduction of textured cavities after the machining tests. The application of LST on endmills is also expected to reduce equipment downtime, which would potentially decrease the number of downtime events from 30 to 4 annually. Therefore, texturing with 45°-channels was found to be a highly effective method for enhancing tool performance and extending tool life in machining processes. The results of this study indicated that laser texturing could significantly reduce tool wear, improve manufacturing efficiency, and optimize production output. This study provided strong evidence that laser texturing was a viable solution for addressing premature wear and minimizing downtime in machining operations.
Key words: laser surface texturing, CNC machining, endmill, tool life, brass

1. INTRODUCTION

Machining processes involve removing material from a workpiece using cutting tools. This manufacturing method is energy-intensive, as much of the energy is converted into heat. The heat generated during machining leads to tool wear, chipping, and eventually tool failure [1], [2]. Furthermore, tooling wastage and its associated costs have been reported to amount to 2-4% of the total machining costs [3], [4].

Laser surface texturing (LST) is a surface engineering technique used to create micro-cavities or textures on various materials and surfaces with high precision [5]. This technique has been shown to significantly improve the performance of tools and mechanical components by generating micro-pools for continuous lubrication, creating a stable fluid film with enough load-carrying capacity [6], enabling debris entrapment, and providing derivative cutting [7], among other benefits.

The type of textured geometry and testing conditions significantly impact the performance of LST. For instance, in a study by Maldonado et al. [8], different geometries—discrete (micro-circles) and continuous (micro-channels)—were textured onto steel blocks for block-on-ring tests. The tests were conducted under varying contact pressure conditions, and the results showed that at low pressures (1 MPa), the micro-circles exhibited the best performance, while the micro-channels (or lines) performed optimally at higher pressure conditions (15 MPa). Torres-García et al. [9] conducted tribological testing using block-on-ring tests on textured blocks with closed or discrete geometries, such as circles, hexagons, and benzene shapes. The results showed a 70% improvement in wear resistance with hexagonal textures, attributed to enhanced lubricant retention and the provision of additional cutting edges. Roushan et al. [7] textured various discrete, continuous, and mixed discrete-continuous shapes on the rake face of a cutting tool for machining PH 13-8 Mo stainless steel. The width and diameter of the textures were also varied. The study found that at low speeds, discrete, continuous, and mixed textures with smaller widths/diameters reduced cutting forces by 12%, 21.4%, and 24.8%, respectively.

LST has also been applied to various types of cutting tools to enhance their tool life and overall manufacturing efficiency. For instance, Maldonado et al. [10] applied LST onto drilling tools for Computer Numerical Control (CNC) drilling of 15-5 PH stainless steel. Micro-channel textures increased the wear resistance of drilling tools by up to 97%. Sun et al. [11] textured micro-grooves, micro-pits, and hybrid textures on cutting tools to improve lubricant flow and retention. The enhanced cutting performance observed was attributed to the textured geometries acting as reservoirs, enabling continuous lubricant replenishment. Pang et al. [12] conducted drilling experiments on Inconel 718 using micro-textured drilling tools with grooved, convex, and pit geometries. The results demonstrated that these micro-textures reduced thrust force, drilling temperature, and tool wear. Additionally, a secondary cutting effect was identified as being facilitated by the micro-textures. Sugihara et al. [13] textured the flank face of cutting tools for high-speed machining of Inconel 718 to enhance tool life, as these tools are prone to failure from chip adhesion due to high temperatures and cutting-edge chipping. The micro-grooves effectively suppressed cutting-edge chipping, resulting in an extended tool lifespan.

In this industrial application, endmills have experienced premature wear, leading to approximately 30 equipment downtime events annually per CNC machining center. In this research, two distinct laser patterns—45° angled channels and dimple arrays—were chosen to texture machining tools used in the manufacturing of C-36000 brass workpieces. C-36000 brass is known for its high machinability and is considered a free-cutting brass compared to other copper alloys. However, the high productivity demand leads to increased wear on the cutting tools. The primary objective of this study was to enhance tool life by reducing wear and improving overall performance. Additionally, the study aimed to minimize the number of downtime events associated with tool failure, ultimately improving the efficiency and productivity of a local manufacturing company.

2. MATERIALS AND METHODS

2.1. Texturing of endmills for machining experiments

Texturing of high-speed steel endmills for machining of C-36000 workpieces was performed using a Dincel ML-desktop fibre laser (30 W) with the following parameters: a speed of 350 m/s, 50% power, wavelength of 915 nm, a frequency of 20 kHz, an 8-mark look, and a hatch density of 0.001 mm to ensure uniformity of the textured cavities. The parameters for the textured geometries (channels and dimples) are shown in Table 1. These parameters were selected based on previous studies performed by our group [8], [10], [14] that demonstrated good tribological performance. A distance of 450 µm was kept between the edge of the tool and the textures to avoid stress concentrations and possible fractures.

Table 1. Parameters for the textured geometries.

Textured geometry	Depth (µm)	Diameter/width (µm)	Distance between figures (mm)	Textured area (%)
45° channel	70-80	100/45°	0.5	16
Dimples	100	100	0.8	16

Figure 1 presents micrographs of the textured endmills with 45° channels (Figure 1a) and dimples (Figure 1b), with the parameters of Table 1.

2.1. Machining experiments

Machining experiments were conducted using a CNC machining center with turning and milling capabilities (Fig. 2) with high-speed steel endmills to machine C-36000 brass workpieces under flooded lubrication conditions. The CNC equipment has an automatic angular speed control. Fig. 3 shows an image of one of the endmills used in the machining experiments (Fig. 3a), highlighting wear and chipping of the edges (Fig. 3b). A total of 1,000 workpieces were machined with the endmill to simulate actual operating conditions and measure wear. Endmills were characterized with a Tescan Vega 3 Scanning Electron Microscope. Surface profiles of textured tools were characterized with an Alicona EdgeMaster optical measurement system. Wear mass loss was recorded before and after the machining experiments with an analytical balance with a precision of 0.1 mg.

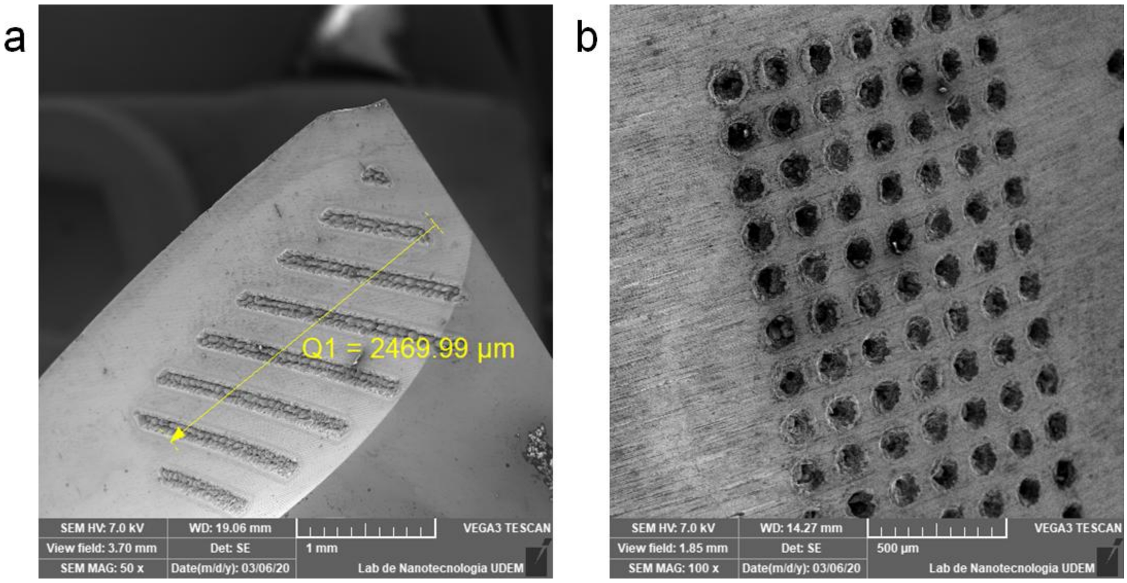

Fig. 1. Image of textured endmills with: (a) 45° channels and (b) dimples.


Fig. 2. Computer Numerical Control (CNC) machining center for milling experiments.

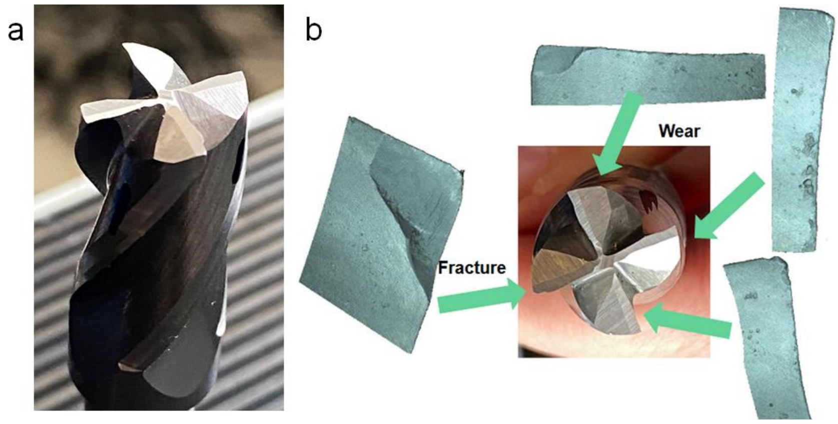

Fig. 3. (a) Endmill used for the machining experiments, (b) upper view of an endmill used to produce the workpieces showing wear and chipping.

3. RESULTS AND DISCUSSION

Fig. 4 - Fig. 7 show micrographs of the endmills before and after the machining experiments for manufacturing the C-36000 brass workpieces. Fig. 4 illustrates an endmill without texturing (Fig. 4a), which after the tests, shows signs of chipping on the cutting edges (Fig. 4b). This damage can affect the quality of the manufactured workpieces and potentially lead to equipment downtime.

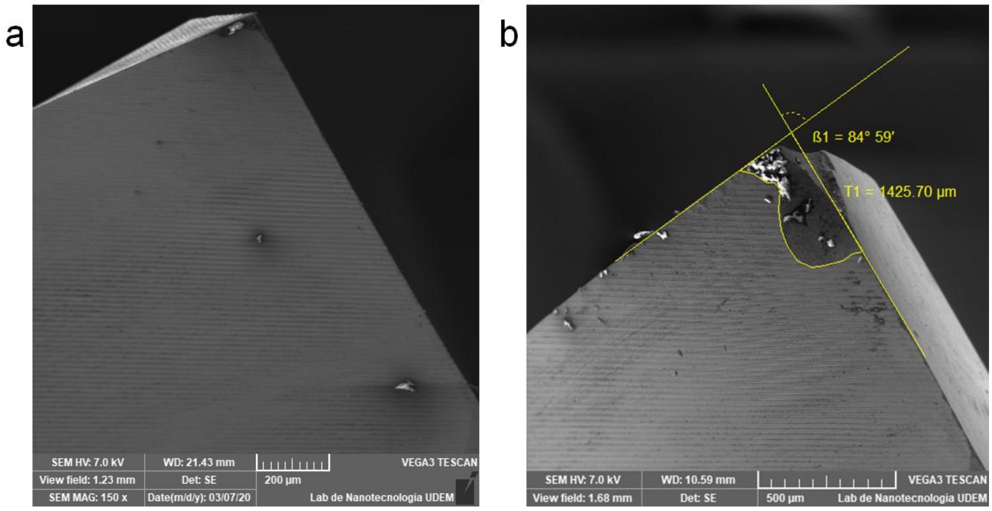

Fig. 4. Image of the edge of an endmill without texturing (a) before and (b) after the machining experiments.

Fig. 5 presents the micrographs of the endmill with the dimple texture before (Fig. 5a) and after (Fig. 5b) machining the C-36000 workpieces. Despite maintaining a distance of 450 µm between the textures and the tool edge, the endmill shows signs of chipping and fracture. Discrete geometries, such as the textured dimples, are effective at ensuring the lubricant remains in the cavities and for trapping wear debris [15]. However, dimples hinder lubricant flow and replenishment [16], making it less effective in reducing wear under the flooded lubrication conditions. Additionally, as the tool began to wear, it reached the dimple textures, leading to stress concentration and resulting in the fractures observed in (Fig. 5b).

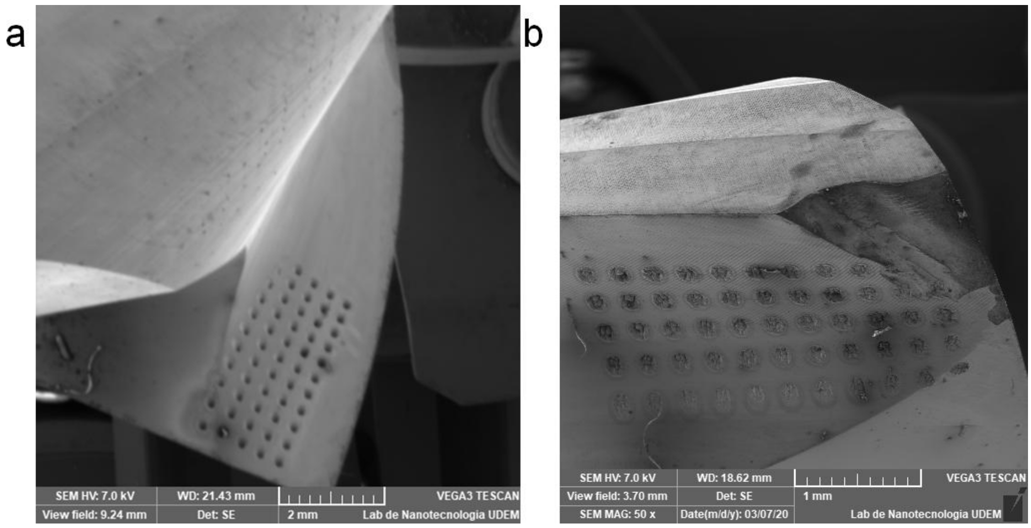

Fig. 5. Image of an endmill with dimple type texturing (a) before and (b) after the machining experiments showing signs of fractures.

Fig. 6 presents the profile of the endmill textured with the micro dimples before and after manufacturing of the C-36000 workpieces, as obtained with scanning electron microscopy. The profiles after the experiments show severe signs of wear, with almost no visible cavities remaining on the endmills, which is consistent with the worn endmill image shown in Fig. 5b.

The micrographs shown in Fig. 7 show an endmill with the 45°-channel texture before (Fig. 7a) and after (Fig. 7b) the machining experiments. Here, endmills show minimal signs of wear of the cutting edge, which can be attributed to the constant lubricant flow and replenishment under flooded lubrication conditions provided by the continuous-type texture (45°-channel) [17]. Additionally, the angles edges of the 45°-channels may have provided a secondary or derivative cutting effect [7], enhancing tool performance by acting as additional cutting edges.

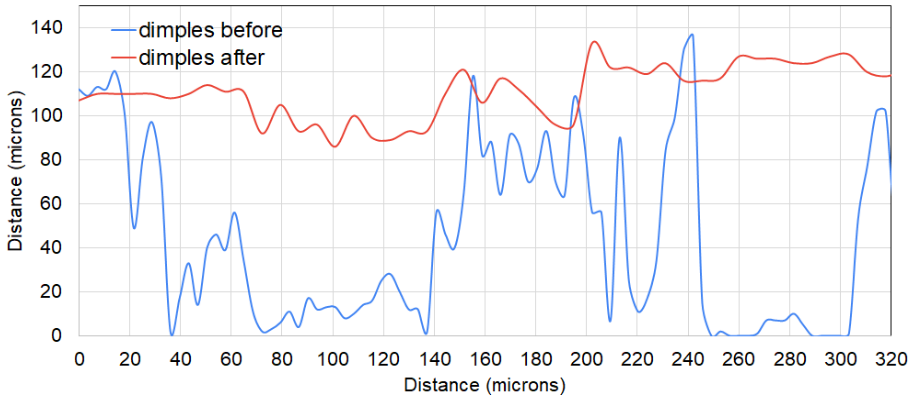

Fig. 6. Profile of an endmill with a dimple texture surface before (blue) and after (red) machining of C-36000 workpieces.

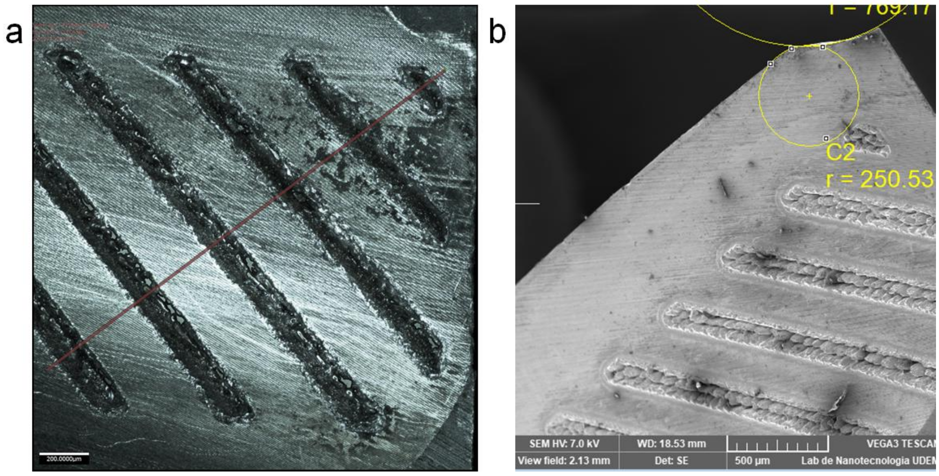

Fig. 7. Image of an endmill with 45°-channel texture (a) before and (b) after the machining experiments.

Fig. 8 presents the profiles of an endmill textured with 45°-channels, showing almost no wear after machining the workpieces. Both profiles (before and after the tests) have very similar features, consistent with the micrograph in Fig. 7b. Only about 5 µm, out of a textured depth of approximately 70 µm, was lost due to wear after the machining experiments.

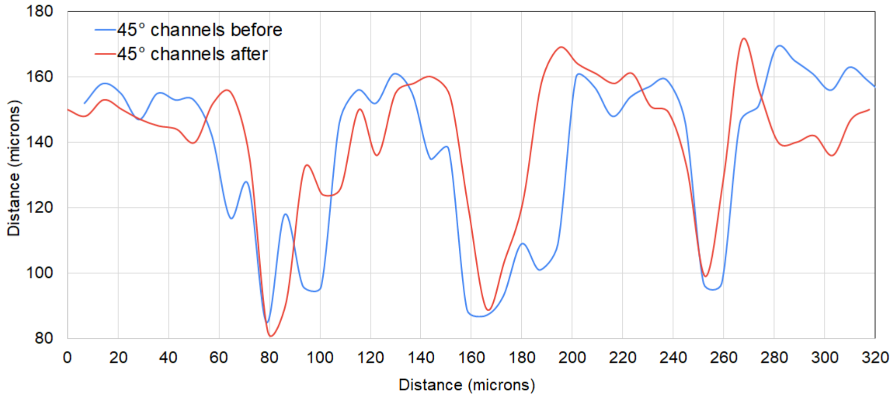

Fig. 8. Profile of an endmill with a 45°-channel texture before (blue) and after (red) machining of C-36000 workpieces.

Fig. 9 shows a plot of the wear mass loss results in mg obtained with the analytical balance by comparing the mass of the endmills before and after the tests. It can be observed that the 45°-channels reduced the wear mass loss by up to 86% (from an average of 2.2 mg to 0.30 mg), whereas the dimples increased wear mass by more than 1200% due to the severe wear that also resulted in fractures. The large standard deviation for the dimple textured endmill is due to the fracture failure mechanism suffered by the tool.

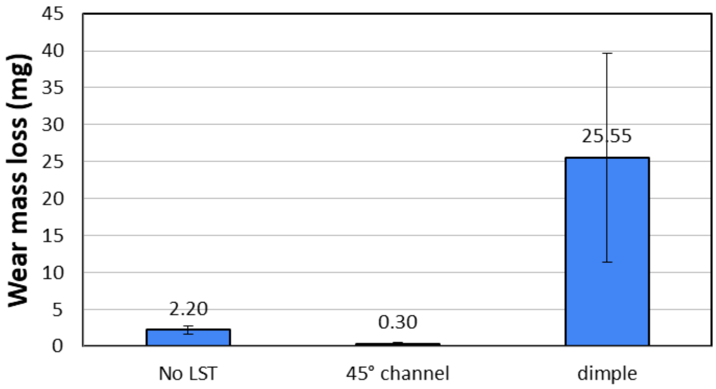

Fig. 9. Wear mass loss after the machining tests of the endmills without laser surface texturing, with 45°-channels, and with dimples.

Based on wear mass loss reduction, the increase in wear resistance of up to 86% provided by the 45°-channels could reduce the number of equipment downtimes from 30 events to 4 events annually due to the improved lubrication [17] and secondary cutting effect [7]. Considering that each equipment downtime lasts about 5 hours for this specific application and approximately 29 workpieces are fabricated per hour, a significant increase in productivity can be achieved, along with improved tool utilization, reduced manufacturing costs, and enhanced overall manufacturing efficiency.

4. CONCLUSIONS

In this study, LST was applied to endmills to evaluate its potential in reducing tool wear, extending tool life, and optimizing the overall manufacturing process. Two laser texturing patterns—45°-channels and dimple arrays—were chosen and applied to endmills for machining C-3600 brass workpieces in an industrial setting. The 45°-channel textured endmills demonstrated an 86% reduction in wear mass loss compared to the untextured endmills, highlighting superior lubricant retention and wear resistance due to improved lubricant flow and the provision of additional cutting edges. In contrast, the dimple-textured endmills experienced higher mass loss due to severe wear and fractures. Overall, 45°-channel laser texturing proved to be an effective method for enhancing tool performance, extending tool life, and improving manufacturing efficiency, with the potential to reduce downtime events from 30 to 4 annually. This study provides strong evidence that LST is a viable solution for addressing premature wear and minimizing downtime in machining operations.

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