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CHARACTERIZATION OF CUTTING TOOL INSERTS WITH LASER SURFACE TEXTURING

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Abstract: This study evaluates the performance of cutting inserts with four different surface conditions—three treated with laser surface texturing (LST) and one untreated—using a CNC milling machine. The objective was to identify the surface condition that optimally reduces energy consumption and tool wear, thereby extending tool life and improving the surface finish of the machined component. Given the widespread use of machining processes in industry, even marginal improvements can yield significant benefits. The laser texturing patterns tested included "S" shaped, crosshatch, and channel geometries. The experimental phase began with the identification of optimal laser parameters to achieve the desired texture depth and an area density of 16%. Each of the four insert types, including the untextured reference, was tested in five machining runs on 1018 steel plates. Key output variables were tool wear (evaluated by profile and radius), surface roughness of the machined part, and energy consumption during the process. Among the tested geometries, the "S" shaped texture exhibited the best overall performance. Compared to the untextured insert, it reduced tool wear by 2.4%, improved surface finish by 18%, and lowered energy consumption by 9.17%. These results highlight the potential of LST as a sustainable and effective technique to enhance machining efficiency and tool durability.
Keywords: Tribology, wear, coefficient of friction, laser surface texturing (LST), tools

1. INTRODUCTION

One of the great concerns worldwide is energy consumption. The demand for more efficient processes that have a lower impact on the environment is increasing. One of the sciences of engineering that contributes to solving this problem is tribology. Machining being one of the highest demand processes in the industry, creates a large area of opportunity to optimize it.
Laser surface texturing (LST) consists of the creation of micro-cavities on the surface of a work tool. These can hold lubricant and wear particles with the advantages of reducing the friction coefficient, the wear produced in the tool, and energy consumption, in addition to, in the case of machining, improving the surface finish of the produced part.
Machining is a term used to describe a group of processes whose purpose is the removal of material and the modification of the surfaces of a workpiece. Among the processes within this group are cutting, in which cutting tools with one or more edges are used, such as turning or milling, abrasive processes, such as grinding, and advanced processes, in which electrical, chemical, hydrodynamic, and thermal methods are used. [1]
Focusing on cutting processes, there are factors that influence this machining operation. These include the parameters of the machine tool (cutting speed, depth of cut, feed), tool wear, and machinability of the workpiece. These influences in the forces, power, temperature rising, tool life, surface finish and integrity, and dimensional accuracy. [1]
Among the most widely used cutting processes in the industry is milling. This is a machining process in which chips are removed using a multi-edged, circular-shaped tool called a milling cutter. The main cutting movement is circular and is carried out by the cutter when rotating on its own axis. The movements are carried out by the part being machined. [1] [2]
Depending on the objective and the piece to be cut, different types of milling are used; among the main ones are peripheral milling, in which the axis of rotation of the cutter is parallel to the work surface. On the other hand, there is face milling, where the cutter is mounted on a spindle that has an axis of rotation perpendicular to the

surface of the workpiece. And finally, the frontal milling in which the cutter is straight or tapered and fits into the spindle of the milling machine. [1]

Laser Surface Texturing, LST, consists of the creation of micro or nano cavities on the surface of various types of geometry. It is a surface treatment with the aim of improving friction resistance, the useful life of the inserts, and reducing energy consumption.

The way that it works is that cavities trap wear particles, and can reserve lubricant, as well as a thin, pool-shaped film of lubricant, which improves lubrication and lowers the coefficient of friction. The advantages of this process are high operating precision, fast and low cost, as well as manipulate the shapes and sizes of the patterns. [10], [11] and [12]

In the study of Elgazzar and Elbashar (2020) [12], they analyzed how the parameters of power and the number of passes affect the creation of the micro cavities and reported the following: The depth increases with the number of passes. With one pass, it was only 1 μm, with 5 it was 6 μm, with 10 passes it was 14 μm, and with 25 passes it was 12 μm. The authors explain that many passes end up damaging; there comes a point at which they no longer change the depth. In addition, a high rim is created. On the other hand, by increasing the power, the depth went from 10 μm with 75 J/mm^2 to 28 μm with 200 J/mm^2.

The authors [12] reported that by uncontrolled increasing the number of passes and the power ends up affecting the texturing, this due to the high amount of energy absorbed by the surface, which causes a greater melting of the material and rapid solidification of the ejected material, which causes splashes around it and the "rim effect" leaving an uneven finish on the surface, so it is important to control these two parameters.

Various authors have studied the effects of laser texturing on the surfaces of cutting tools during different machining operations, and an improvement has been observed in various properties, such as friction between the tool and the machined material, and a reduction of wear in the cutting tool. Among these authors are: PhD Laura Peña-Parás, PhD Demófilo Maldonado Cortés, Toshiyuki Enomoto, Tatsuya Sugihara, and Deng Jianxin. [17-20].

In their articles they show that the application of laser texturing in cutting tools helps with the reduction of energy consumption, improves the roughness of the machined part, better resistance to wear in the tool, reduction of friction between the tool and the work piece and reduction of cutting forces, resulting in an extension in the useful life of the tool and a better surface finish of the machined material. Multiple tribology studies aim to analyze the correlation between the texturized surface area of a material and its coefficient of friction (COF). In a study by Šugárová and Rosenkranz [13], it is mentioned that to texturize an area between 5 and 20% of the total surface area decreases the surface of contact and the COF. On the other hand, to texturize an area above 20% of the total surface area is detrimental to the wear of the material, because it increases the COF and the wear rate.

In the article "Development of a methodology for improving the tribological properties in die processing" [16], it is proven that the least wear and COF are obtained with a texturized surface area of 16% of the total surface area, which is consistent with the range mentioned above by Šugárová and Rosenkranz.

The objective of this study is to analyze the cutting tool inserts performance texturized with three different geometries ("S" shape, "Crosshatch", and "Channels") and test on the CNC milling tool, to determine the best geometry to decrease the energy consumption and wear rate of the insert, thus, increasing its lifetime and improve the surface finish of the machined part.

2. MATERIALS AND METHODS

The following flowchart (Figure 1). shows the stages that were carried out during the development of this project, going from the familiarization with the laser equipment to the analysis of the test results. The left column of the diagram shows the inputs for each phase, and the right column shows the outputs.

The resources needed to carry out this project were the Fiber Laser Marking Machine, model XM-20D, Dincel brand, and the Ezcad program to texturize the inserts; the IF-EdgeMaster G4 Vc2 Alicona, to analyze wear in the inserts, and the Haas CNC Milling Machine, Model VF-2D, to machine with the inserts. The inserts used were KORLOY brand of carbide coated with titanium aluminum Nitride, and for the machining, AISI 1018 steel plates and lubricant of mineral origin, Tribos Sol 320, in a concentration of 95% water and 5 % lubricant were used. The application time of LST for each insert is about 65 seconds.

2.1. Geometries

Texturized area percentage: According to the state of the art, it was decided to texturize 16% of the total surface area in the inserts of this project (Figures 2 and 3).

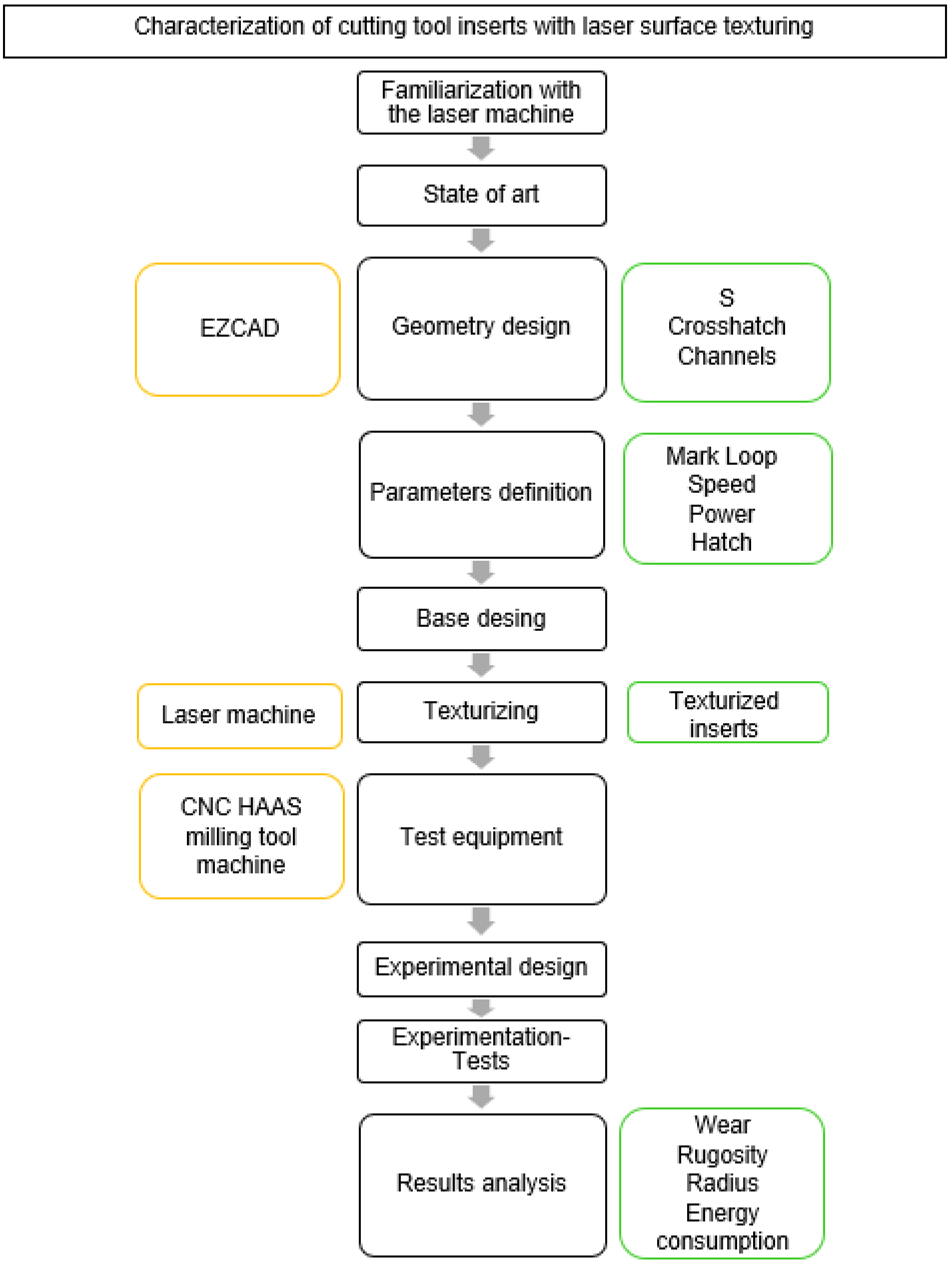


Fig. 1. Methodology and steps used

Fig. 2. Area to be texturized

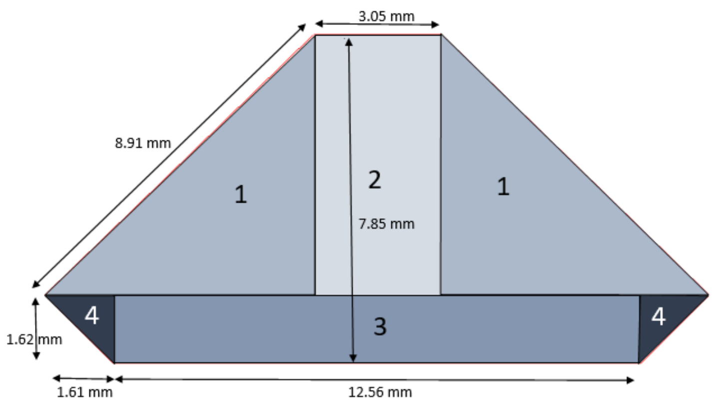


Fig. 3. Division of the area to be texturized

In Table 1 it is shown the division in parts of the area to be texturized, the surface area of each part, the quantity of equal parts in the figure, and the total surface area to be texturized are shown. This area is 81.72 mm^2, so 16% of this area is 13.07 mm^2.

Table 1. Calculation of 16% of the total surface area on the insert

Parte	Area (mm^2)	Quantity	Total area (mm^2)
1	19.842	2	39.685
2	19.001	1	19.002
3	20.410	1	20.410
4	1.312	2	2.264
		Total	81.721
		Texturized area (16%)	13.075

2.2. Geometry design

The following geometries were selected to be part of this project due to the data mentioned in the state of the art, where two authors (Šugárová and Maldonado) affirmed that these geometries were the ones with the least COF and wear obtained.
There are three geometries:
-"S" shape: It was made with the text function in the EZCAD software, and a crosshatch pattern was added inside the S shape so the texturing had depth. The result is shown in Figure 4.

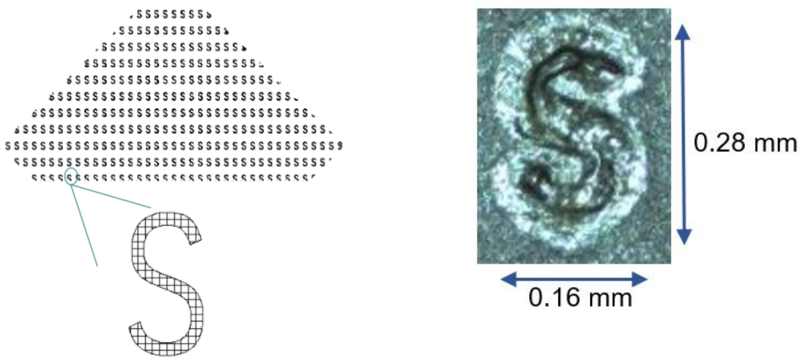


Fig. 4. Geometry "S" design and dimensions

With these dimensions, the texturized area of one pattern of "S" is 0.0448 mm^2. To fulfill the condition of 16% of the total surface area, a total of 290 "S" patterns are required.
-Crosshatch: To create this geometry, horizontal and diagonal lines were used (Figure 5);

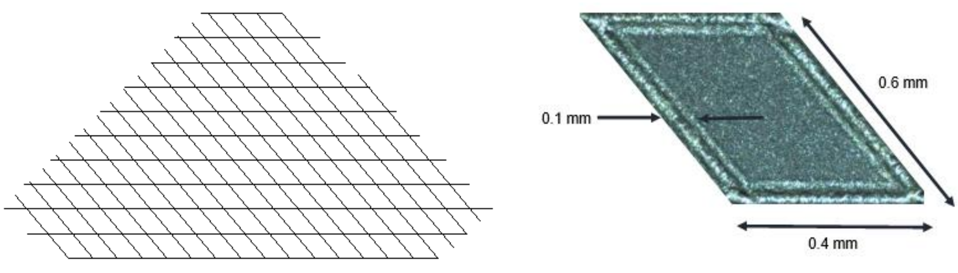


Fig. 5. Geometry "Crosshatch" design and dimensions

Taking into consideration these dimensions, the texturized surface area is 0.16 mm^2 of one pattern of "Crosshatch". To fulfill the requirement of the 16% texturized surface area, a total of 81 patterns of "Crosshatch" are necessary.

-Channels: To make this geometry in the EZCAD software, the function of shapes was used (figure 6), utilizing rectangles and half-circles. This geometry was made with the same dimensions used in the article "*Enhancing tool life, and reducing power consumption and surface roughness in milling processes by nanolubricants and laser surface texturing*" [21]. In addition, a crosshatch pattern was added so the texturing could have depth.

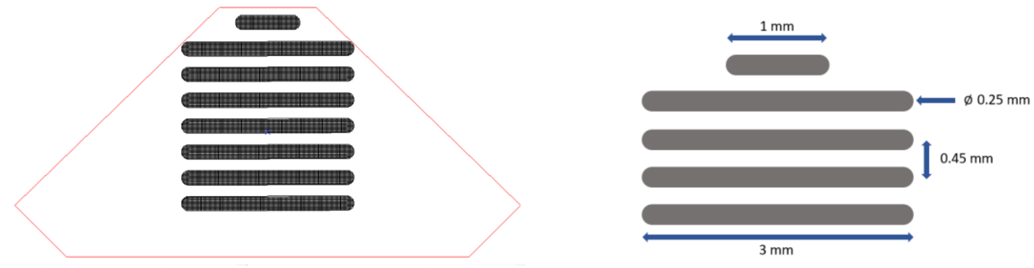


Fig. 6. Geometry "channels" design and dimensions

With these dimensions, the total texturized surface area is 5.39mm^2. As the same geometry that the article mentioned was used, the number of channels to meet the requirement of 16% of area texturized was not taken into account. But the total surface area of this geometry to be texturized was calculated using these dimensions, and a value of 6.6% was obtained, which is within the range suggested by Šugárová [13].

-Volume removed: In Figure 7 and Table 2, the parts in red are the ones considered by the Alicona to calculate the volume removed after the texturing.

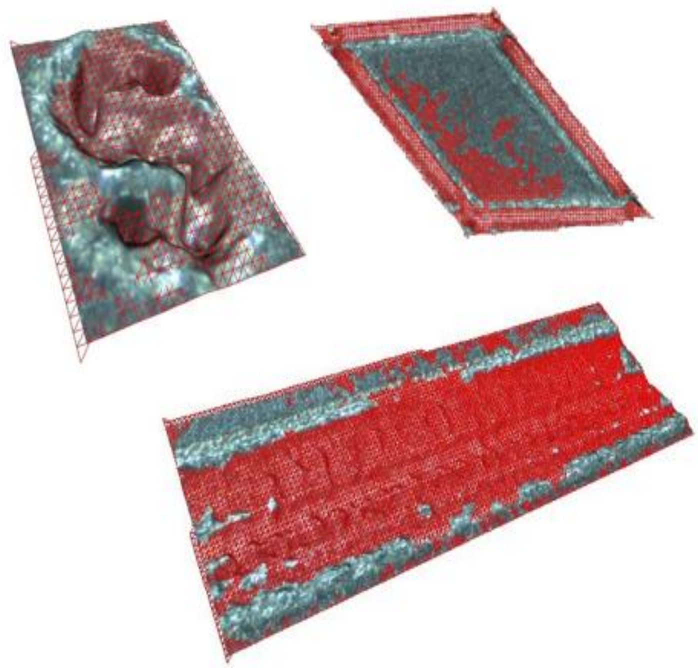


Fig. 7. Removed volume of the 3 texturized geometries (S, Crosshatch, Channels)

Table 2. Total removed volume in each geometry

	Removed volume in 1 pattern μm^3
"S"	7.9×10^7
Crosshatch	5.7×10^7
Channels	2.1×10^7 *

*The removed volume in 1 pattern of the Channels geometry was measured in 1 mm length.

2.3. Machining parameters

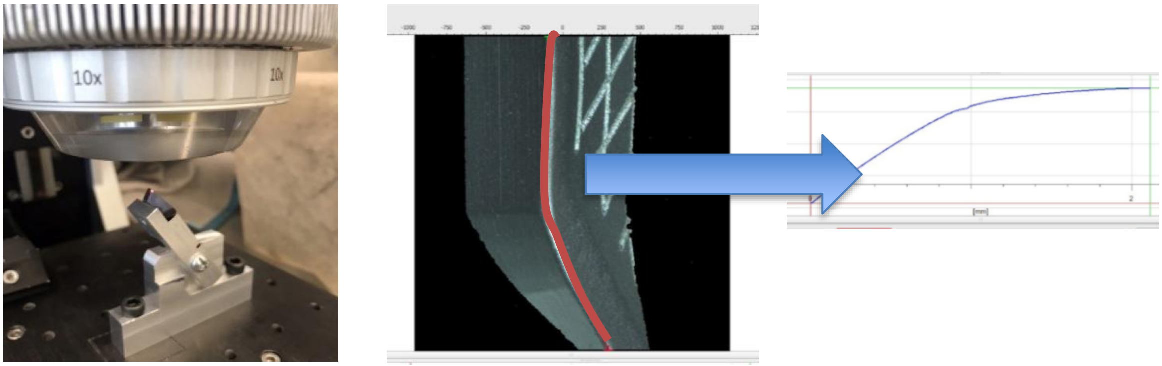
The 1018 steel plate was machined using the Haas CNC milling machine, and a G and M code program was created that would completely remove a layer of material from the plate. The program was used in the metric system and in absolute coordinates, and the parameters used were: cutting speed of 1750 rpm, depth of each pass of half a millimeter, and feed of 200 mm/min. We wanted to observe the progression of wear until fracture, so, due to the limited time available in the laboratory, these were the appropriate parameters to perform the desired number of tests.

In each pass, a single insert was placed in the milling cutter, and each test consisted of 7 passes for each insert, without texturing, with S geometry, crosshatch, and channels. In total, 5 tests were carried out.

2.4. Wear profile

The wear measurement was carried out with the Alicona (Figure 9). The area of interest to be measured was the edge of the insert with which it was machined, so to have a precise and repetitive measurement of the edge between the different inserts, an aluminum tool holder was used that allows the insert to be placed at an angle of 135°, as is shown in Figure 8.

After obtaining the insert edge measurement, the wear profile curve was obtained using the ProfileFormMeasurement function of the Alicona. To achieve this curve, a line is drawn along the cutting edge, and the result is a group of points that form the wear profile of the insert (Figure 8).



a b

Fig. 8. a) Aluminum tool holder with insert, b) Measurement of the wear profile and its curve ("y" and "x" axes are in microns)

The insert edge radius was also a variable of interest, and to obtain values of this, the Alicona was also used. Obtaining the insert edge radius makes it possible to quantify the progression of wear, since a greater radius indicates that the insert is still sharp, therefore less worn. However, a smaller radius indicates loss of sharpness in the tool, therefore, more wear. The measurement to obtain the radius is basically the same as for the wear profile, only that in this case, the line is drawn perpendicular to the corner of the insert.

To obtain values of the surface roughness of the 1018 steel plate before and after machining it (Figure 9), the Alicona was used. In this case, the Profile Roughness Measurement function was used. To get the roughness value, a line is drawn perpendicular to the direction of the lines of the plate material.

2.5. Energy consumption

Lastly, among the data displayed by the CNC milling machine during machining operations is the spindle load in kW (Figure 10). Since all the inserts had the same operating time, this data was used to measure the energy consumption variable. The value of the spindle load is shown in real time during the operation, so for each test, the value taken was the highest. No significant savings were found in friction reduction (energy consumption), but we believe that with the machining of more demanding steels, this will be an additional savings factor.

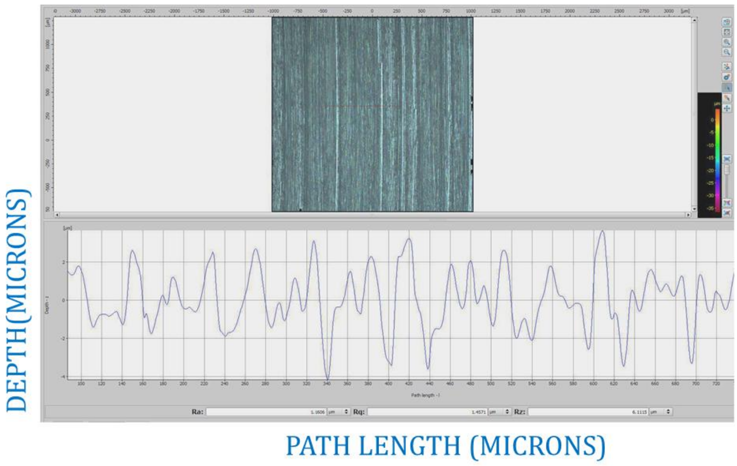


Fig. 9**.** Surface roughness measurement

Fig. 10. CNC milling machine display highlighting spindle load

3. RESULTS AND DISCUSSION

3.1 Wear profile

To quantify the progression of the wear profile in the inserts, the area under the curve of the profiles was obtained, and the NX software was used to obtain this area. The loss of area after the passes was considered as material removed or lost in the insert.

After obtaining the average of the wear progression in each pass of each insert, it was observed that the pass in which there was a critical removal of material was in the sixth one, therefore, for a better visualization of wear between the different inserts, a fitted graph was made showing the average wear profile of pass 6 of each insert compared to the wear profile of a new insert.

As can be seen graphically (Figure 11) and quantitatively (Table 3), the original insert profile is the orange line. The insert with the highest % of material removal was the insert without texturing with 5.22% (green line), followed by the one textured with “S” geometry with 3.24% (yellow line), and then the insert with channels geometry with 2.89%. The cutting tool that presented the least wear was the insert with crosshatch geometry, with a percentage of material removed of 2.30% (red line).

The percentage of removed material was calculated against the area under the curve with the original reference of the new insert.

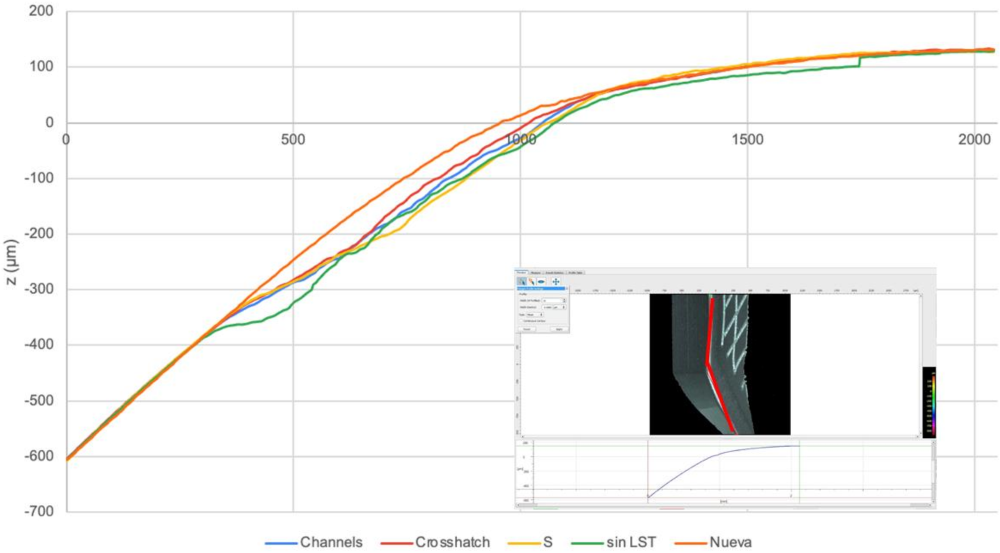


Fig. 11. Average wear profile in the 6th pass of the tested inserts vs the wear profile of a new insert

Table 3. Average % of removed material in inserts with the different geometries.

	% of removed material
Non-textured	5.2235
"S"	3.2499
Channels	2.8950
Crosshatch	2.3060

4. CONCLUSIONS

The insert wear percentage results show reductions of more than double for the crosshatch textured insert compared to the non-textured insert. In the manufacturing industry, tool savings of over 10% are considerable. Although the steel is very easy to machine because it is 1018, subsequent studies with more demanding steels promise similar savings. It is feasible to sacrifice the savings found in wear by increasing machining speeds and depths to increase the productivity of the machining process. One of the explanations why the crosshatch geometry performed better is that there are more contact edges between the workpiece and the cutting insert.

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Conflicts of interest: There is no conflict of interest.

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