

Improvement of Tribological Properties through the Application of Laser Surface Texturing and Nanolubricants in CNC Equipment Elements

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ABSTRACT

This investigation shows a solution to improve the problem of premature wear in the screw ball elements of CNC turning lathe. Screw ball element is an essential component for the movement of a lathe operated by computerized numerical control (CNC). Four ball tribotester T-02 was used to find the best anti wear properties on lubricants with Halloysite Nanotubes (HNTs) then, through the use of laser surface texturing (LST) micro cavities with 15 μm of depth were added to the surface of the screw and with the addition of Halloysite Nanotubes (HNTs) in the base lubricant; tribological performance was upgraded. Important achievements were reached: 38 % of increment in wear resistance and reduction in surface finished roughness (Ra) up to 11 % in the CNC machine element (screw ball).

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1. INTRODUCTION

The need to solve wear and maintenance problems in the machine's elements has led to the development of new technologies such as: laser surface texturing (LST) and the addition of nanoparticles (NPs) in lubricants.

LST it's a technique that involves the creation of micro cavities on the surface of the machine element or tool with a specific pattern (circles, squares, lines, triangles, etc.), which serves to operate as micro-traps to capture debris particles of wear [1]. Also this technique improves

tribological properties, such as load carrying capacity; wear resistance and reduction of the coefficient of friction (COF) [2,3]. This technology has been applied in different industries e.g. in the automotive, aerospace among others. Another example is the use of LST in piston rings and cylinders [3-5], looking for COF reduction and improving the efficiency of the engine. This technique also has been applied in the interaction of materials different than metals, for example on the metal-mechanic industry has been used for reduction of wear between different materials, e.g. sliding contact between metals and ceramics, where there LST produced positive results [6].

A nano lubricant can be defined as a lubricant in which NPs were added in order to improve its performance [7]. A positive result has been produced when adding NPs to lubricants such as improvements in tribological properties like reduction of COF and improvement in wear resistance [8].

Plenty of studies show the benefits of the use of this technology [8-14,18,19-20]. The nanoparticles selected for the development of this project were TiO₂, CuO and Halloysite Nanotubes HNTs due their properties and characteristics such as they are natural, inexpensive and ecofriendly. Peña et al. showed that the HNTs, reduced loss of wear volume and the COF by 70 % [13].

2. TECHNOLOGIES AND EXPERIMENTAL METHODS

2.1 FOUR BALL TEST

In order to select the best concentration of NPs on base lubricant, tribological tester was used. A tribotester called four-ball was selected. The method to be used will depend on the working conditions (mainly contact pressure) of the machine element to be improved.

There are two types of tests that can be developed with the four-ball T-02 tribotester machine depending of the applied pressure: the extreme pressure test (EP) (contact pressures greater than 2,000 N/mm²) and the anti-wear test (AW) (less than 2,000 N/mm²). There are different parameters to be considered in each kind of test. In this research anti-wear tests were carried out and the parameters are described in Table 1.

Table 1. Standard Parameters by ASTM (D4172-94).

Lubricant Temperature	75 °C
RPM	1200
Load	392 N
Time	3600 s

Table 2. Working conditions.

Variable	Description
Lubricant	Vactra
RPM	2,500
Linear velocity	15 m/min
Contact Pressure	7 Mpa

Prior to star the experimentation process it's important to determinate all the variables that will be considered, mainly the contact pressure. The working conditions of this research are detailed in Table 2.

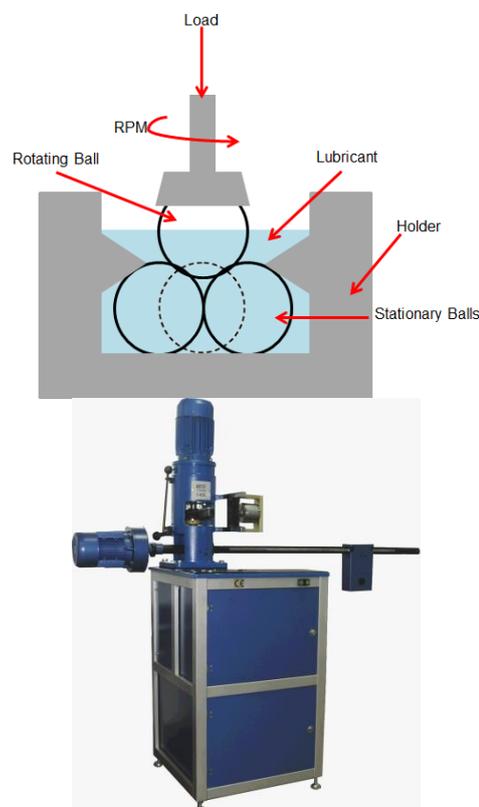


Fig. 1. Representation of the four-ball T-02 tribotester.

As is showed in Fig. 1, the test consists in three (0.5 in diameter) chromium steel balls (that remain static) covered with lubricant; a fourth ball is placed at the top of them generating a three-point contact. A load of 392 N is applied on the lower balls for a period of 3600 seconds with a speed of 1200 RPM; this produces a Wear Scar Diameter (WSD) on the static balls. From the measurement of the WSD the anti-wear properties of the lubricant can be calculated.

2.2 Wear Measurement

For the interpretation of the results, the WSD of each ball was measured. For each test three lower balls are used, three repetitions of each test are performed, the total number of different combinations was 8 so 24 WSD measurements were obtained.

The base lubricant and current one in the process is called Vactra. Nanoparticles of TiO₂ at

0.05wt% which demonstrate in previous work to be the best wt% concentration [21], CuO at 0.01, 0.05 and 0.1 wt% and HNTs at 0.01, 0.05 and 0.1 wt% was added to the base lubricant.

From each group three repetitions were made, varying the nanoparticles (TiO₂, CuO and HNTs) and their concentrations (0.01, 0.05, and 0.1 wt%) in a base lubricant (Vactra).

The results of all NPs concentrations on the base lubricant are presented in Fig. 2.

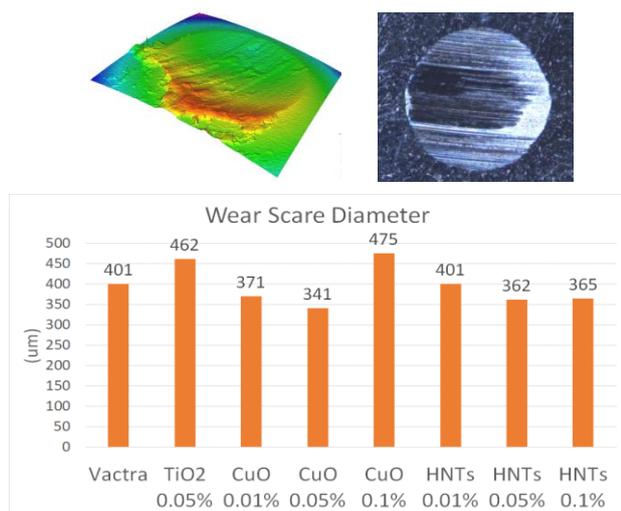


Fig. 2. Wear score 2D and 3D and results of WSD.

Because of performance and also cost benefit, the wt% selected was HNTs at 0.05 even that the best result of WSD is related to 0.05wt% of CuO nanoparticles concentration (Fig 2).

2.3 Laser Surface Texturing (LST)

In the LST tests, an optimal texturing pattern was defined (hole diameter and depth), based on previous tribological investigations performed to evaluate wear resistance in laboratory probes [16]. There were identified the best cases of wear performance for circles pattern with a density of 16 % of applied area, represented in Fig. 3.

The micro cavities depth in which the laser penetrates on the surface element depends of the material properties, which explains why tests were carried out to determine the appropriate intensity of the laser.

The experimental matrix to define the parameters in the laser tests to get a depth of 15 µm is presented in Table 3.

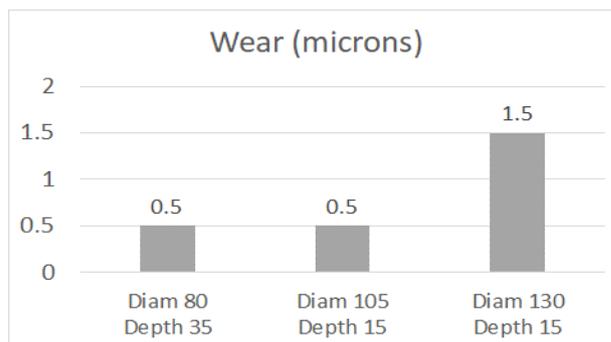


Fig. 3. Best cases of wear performance. Diameters and depths of micro cavities with optimal wear results in laboratory probes [16].

Table 3. Laser Intensity Test.

Laser Intensity Test (Watts)		
# of test	% Intensity	# of repetitions
1	100	1
2	100	2
3	100	3
4	50	1
5	50	2
6	25	1

The depth of the micro cavities generated by the LST tests were measured by the 3D surface analyzer Alicona Edgemaster in order to determine the optimal combination of intensity and repetitions to get a depth of 15 µm. After analysing the results, the combination with closer depth was 100 % of intensity and 2 repetitions as it can be appreciated in Fig. 4. It's important to remark that the value of the diameter is independent of the % of intensity and this parameter (diameter) remains constant.

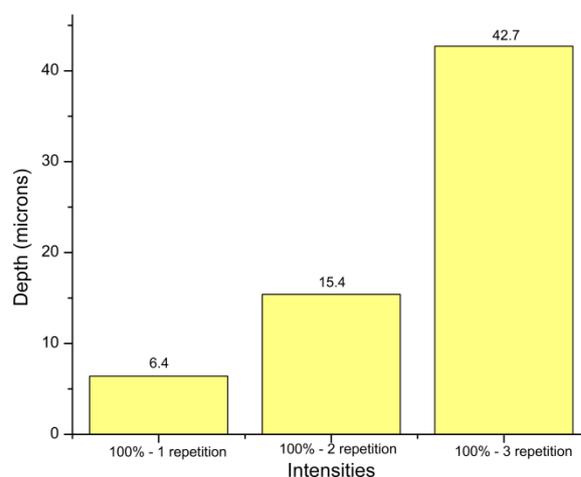


Fig. 4. Laser Intensity test results.

An optical fiber doped with Ytterbium laser was used with a wavelength of 1070 nm, frequency of 15 KHz and a power of 20 Watts.



Fig. 5. LST circle pattern on ball screw element.

Then the CNC ball screws elements were partial texturized in the edges (Fig. 5) to have a reference point with non-texturized areas; also they were full texturized in the center due to the fact that it's the surface area that receives more wear.

3. RESULTS

After analyzing the measurements on the ball screw element with the 3D surface analyzer Alicona Edgemaster, a roughness difference was determined before the beginning of the pilot test and after 4 weeks of duration of the pilot test. The roughness diagrams are represented in Figs. 6 and 7.

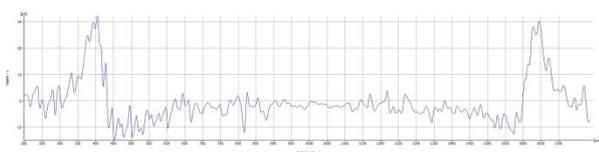


Fig. 6. Roughness diagram of the ball screw element profile before pilot test.

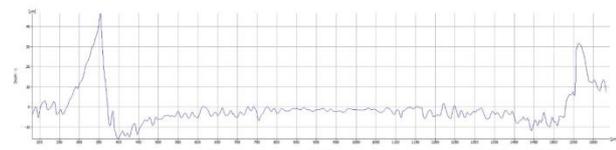


Fig. 7. Roughness diagram of the ball screw element profile after pilot test.

It was found that the Ra of the ball screw element before starting the pilot test was 5.59

μm, and the same screw ball element after the pilot test had a Ra of 4.95 μm (difference of 0.64 μm). According to Noor et al. [15] the Ra usually accelerates the process of wear and produce damage in surfaces.

Along with the pilot tests, some production pieces performed on the CNC lathe were measured. The results were compared with another CNC without LST and NPs in order to have a point of comparison. A specific diameter of the produced part on CNC was measured in order to track process capability performance (Fig. 8). Two important quality control indicators were tracked in order to observe the process capability performance (Cp and Cpk).

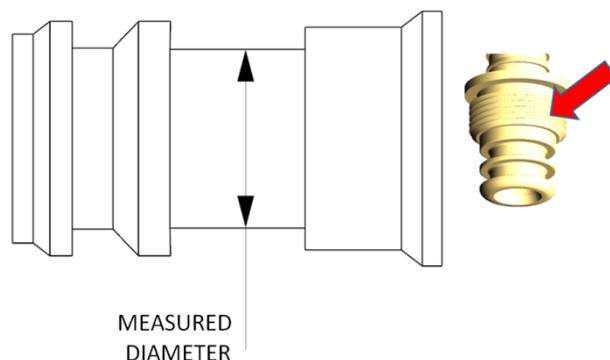


Fig. 8. Measured diameter of the produced part on CNC equipment.

On table 4, CNC 10 represents control values on production without the LST and nano lubricants (HNTs at 0.05 wt%), while Piece 1, Piece 2 and Piece 3 were the 3 different pieces machined in the pilot test.

Table 4. Results of Cp and Cpk.

Indicator	CNC 10	Piece 1	Piece 2	Piece 3
Cp	2.66	4.70	5.01	3.47
Cpk	1.45	3.67	4.48	3.26
Optimal Process	1.33	1.33	1.33	1.33
Robust Process	2	2	2	2

Values up to 1.33 on Cpk and Cp values indicates a good performance and stability of the manufacturing process and values above 2 means a great robust process; so values reached of 4.7 for Cp on piece 1 and 4.78 for piece 2 for Cpk shows a great increment on process capability thanks to the addition of NPs and LST.

Additionally, during the test it was possible to obtain three measurements on the screw ball

element; the first one was before starting the test, the second one was obtained 21 days after the test started and the third one was obtained 1 month after the test began.

The measurements of the screw element without NP and LST were obtained for a screw element that has been working for 5 years; with the measurements obtained, a prediction line was made. With the prediction line was possible to approximate the amount of wear that would be produced in the screw after 21 and 34 days.

The results are presented in Table 5 (wear expressed in μm).

Table 5. Wear results

Applied Technology		Wear n microns		
NP	LST	After 21 days	After 34 days	Improvement %
NO	NO	0.38	0.62	NO
YES	NO	0.31	0.5	20 %
YES	YES	0.24	0.39	38 %

The addition of NPs produced an improvement of 20 % meanwhile the combination of LST and the addition of NPs generated an improvement of 38 %.

Similar results are presented by the author in previous developments using LST and NP's technics in which the values of COF and wear (in laboratory probes, tools or machine elements) was improved [3,13,16,19-20].

4. CONCLUSIONS

Cp and Cpk demonstrated to be class leader after implementing LST and NPs technologies in the current process for the pilot test, producing better quality pieces also increased the CNC element's useful life.

HNTs are characterized by their cylindrical shape and by generating a rolling effect and due to the working pressure and the low hardness of the nano particles, they vanish on the surface forming a "tribo film" which serves as a surface spacer and reduces wear and friction coefficient [17,18].

The addition of HNTs decreased the Ra of the screw ball element by 11 %.

The objective of the LST was fulfilled as the micro cavities served as containers for both the lubricant and the wear particles, which resulted in a prolongation of the lubrication process.

The best improvement in the process was obtained with the combination of NPs and LST that's demonstrate a synergistic effect between the two technologies (LST and NPs).

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