Development of laser surface texturing for applications in extreme conditions

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Abstract

Laser surface texturing has been developed to modify steel and ceramic surfaces prior to physical or chemical vapor deposition of hard coatings. These surfaces were ablated using nanosecond pulses from a Cu-vapor laser or from a Nd:YAG, at intensities of GW/cm^2. The laser surface treatment modified the materials surface properties improving adhesion of the coating on the substrate, in comparison to unmodified surface condition, due to supposedly controlled roughness and microstructural changes. The laser-textured drills have a life expectation ten times greater than conventional ones when drilling stainless steel at a cutting speed of 33 m/min. The laser textured forging dies last three times more than conventional or nitrided ones under industrial conditions. In the case of face milling compact graphite iron and mould steel with cemented carbide inserts, the lasered tools have the same lifetime of the commercial micro-sand blasted tools. The laser texturing technique has been also studied for application in extreme conditions, such as deep waters, highly abrasive conditions and space environment. The engineering of micro- and nano-features at the materials surfaces show promising to the development of parts and systems capable to resist in adverse situations.

Keywords: laser surface texturing, lifetime testing, cutting and forging tools, industrial practice

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1 Introduction

Worldwide metal working companies face daily the great challenges for reaching adequate production rate, minimize unscheduled stops, reduce retooling and even control waste generation. In order to achieve these goals, advanced tooling technology such as micro and nanograined materials and multi-layered functional coatings have been employed [1, 2]. Some tooling companies and research groups are also studying the phenomena occurring at the interface between surface and coating of cutting tools, moulds and dies. These studies aim primarily the development of more durable and more wear, impact and high temperature resistant tools, for high speed machining or difficult-to-machine base materials.

Several important properties for tools are related to its surface quality, including finishing and coating structure and thickness. One possible route to control the surface properties is through laser processing. Laser processing could be envisaged in a number of ways, like hardening, shot penning, carburising, nitriding, etc., depending on the desired properties [3]. This work focuses on a processing technique which has been studied in the Institute for Advanced Studies of Aeronautic Technological Centre in Brazil for the last eight years: laser surface texturing. It had been primarily used for improving the performance of computer hard-disk drives by creating bumps that optimizes the interaction between the drive head and the writable magnetic surface [4]. Few years after, high-power CO_2 lasers have been used to create periodic pattern on steel mill rolls [5, 6].

The texturing of surfaces using laser beam presents a potential to replace, in some applications, other conventional techniques, such as sand blasting and chemical milling. A focused laser beam produces depressions on surfaces that can be surrounded by a ring of recast material. The wavy topography of the consecutive bumps is reproducible and can be controlled by varying the parameters related to the laser-material interaction (beam power, intensity distribution and pulse form, frequency and duration). The laser processing can be carried out either by scanning the beam over the surface or by using ablation masks after the beam expansion [7]. The incident energy and the interaction time between the laser radiation and the material surface determine whatever a large area with local heating is going to occur or a small and precisely limited region is removed. Further to laser processing, the textured surfaces are coated by conventional PVD or CVD methods and thus the difference between conventional and textured tools belongs to the surface preparation prior coatings.

The laser surface texturing technique has been also considered for highly abrasive conditions such as rock mining. Recent developments for the oil industry have shown promising results for lubrication and tool lifetime after laser texturing. The creation of dimples in selected regions of tools has been associated to the reduction of friction forces during drilling.

This work aims on the development of laser texturing for some tools and dies using a CuHBr pulsed laser source. The objective is to enhance lifetime of the high-speed steel drills, cemented carbide inserts and tool steel dies by producing a controlled texturing before coatings deposition. Differently from previous works [8 - 11] where the objectives were to discuss the methodology, microstructure and resilience of the coating, here only the lifetime aspects are considered. Every type of tool has been tested under industrial conditions in order to gather the real possibilities of the technology.

2 Experimental

A pulsed CuHBr laser with wavelength $\lambda = 510$ nm, pulse duration tp = 30 ns, circular beam with 30 μm focal diameter and 13.8 kHz pulsing frequency was used for laser surface texturing. A scanning-head unit controlled the beam movement over the work surfaces. Figure 1 shows the current setup for the laser surface texturing. The laser system comprises a computer-controlled laser

(1), a collimator for beam expansion (2) and a scanning head guiding the laser beam over the workpiece (3). Laser surface texturing is achieved by scanning the workpiece with parallel laser tracks distanced 30 μm from each other. The transverse beam speed was programmed based on the number of pulses planned to irradiate on each point of the work surface.

The materials used in this work are:

a) 10 mm diameter helical drills with point angle of 118° and dimensions according to DIN 338, made of AISI M2 high-speed steel tempered and quenched with final hardness of 62 HRC. The surface was coated with titanium nitride (TiN) after laser surface texturing. For drills, the laser beam is scanned in a line while the drill is rotated at a given speed given a typical helical pattern. These tools were used to cut AISI 304 stainless steel workpieces.

b) Commercial cemented carbide inserts for rough milling machining (ISO equivalent P25, M15 and K30) composed of 9% cobalt binder, 90% tungsten carbide and 1% other carbides (TiC, TaC and NbC). The carbide grain sizes are 3-5 μm. The conventional inserts were micro-sand blasted before coating. Both textured and conventional inserts were CVD coated with $TiCN+Al_2O_3+TiN$. These tools were tested in face milling of FV450 compact graphite iron;

c) The forging dies have 6 cm diameter, 4 cm height and are made of tool steel M35. Conventional dies were only machined and cleaned with an acid solution. Both textured and conventional dies were PVD coated with AlCrN. For comparison purposes, some nitrided dies were also tested. The dies have been used for forging piston pins and connecting rods made of cemented carbon steel.

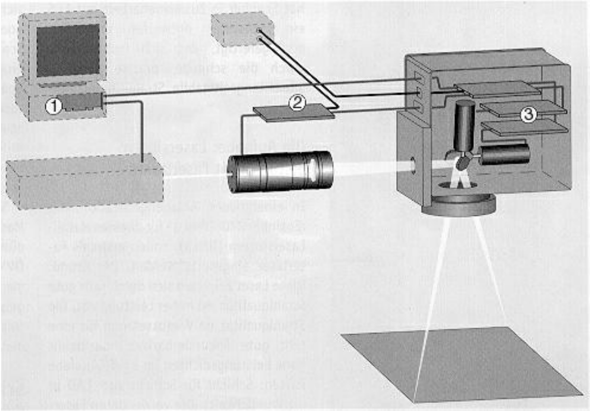

Fig. 1: *Laser system.*

3 Results and Discussion

Conventional and textured tools were tested in industrial conditions. Further information about the laser parameters and microstructural features are available in the literature [8 - 11]. Due to proprietary reasons some aspects of the laser treatment would not be revealed.

3.1 Drilling

The goal of these experiments is to verify the influence of laser texturing carried out before the TiN coating application in the drilling performance of high-speed steel drills when machining AISI 304 stainless steel. The laser intensity was 265 MW/cm^2. The input variables were cutting speed (22, 27.5 and 33 m/min) and the substrate condition (textured and conventional). The output variables were feed force, drill wear and number of holes machined, up to a limit of 100 holes per drill. Some experiments were interrupted before this number of holes, due to either the breakage or a large damage to the cutting edge.

The number of holes carried out in each experiment can be seen in Table 1. It can be observed in this table the excellent performance of the textured drills compared with the conventional ones for cutting speeds (v_c) of 27.5 and 33 m/min. Even in the experiments with v_c = 22 m/min, where both kinds of drills were able to drill the same number of holes, the textured drill presented a much smaller flank wear than the conventional, after 100 holes drilled.

Tab. 1: *Number of holes drilled in each experiment and condition of the drill in the end of the experiment*

v_c	Substrate condition	Number of drilled holes	Drill condition at the end of the experiment
22 m/min	Conventional	100	Flank wear = 0.21 mm
	Textured	100	Flank wear = 0.11 mm
27.5 m/min	Conventional	14 - 17	Broken
	Textured	100	Flank wear = 0.12 mm
33 m/min	Conventional	7 - 8	Broken
	Textured	70 - 100	Flank wear = 0.09 mm

3.2 Milling

For the P20 mould steel face milling machining tests, it was prepared two groups of inserts: one lasered with 239 MW/cm² pulses and the other with 410 MW/cm² pulses as pre-coating process applied over the tool rake and clearance surfaces. The scanning speed was changed in order to allow the superposition of a number of laser shots, as: 64 pulses for an intensity of 239 MW/cm² and 2 pulses for an intensity of 410 MW/cm². These values were obtained from various tryouts using as output results the extension of surface cracks after conventional Rockwell C testing. The tool life results are showed in the Figure 2.

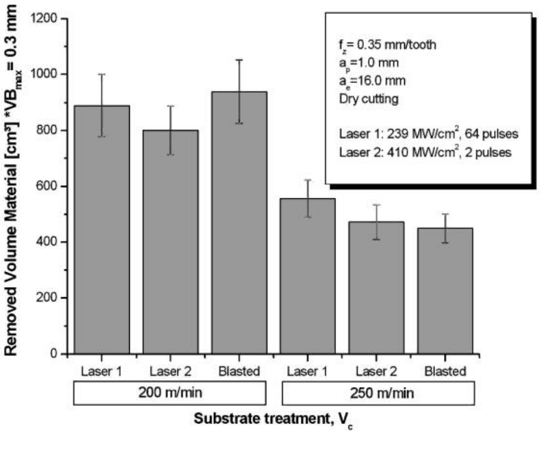

Fig. 2: *Experimental laser treated vs. commercial inserts life comparisons in P20 mould steel milling.*

With the cutting speed of 200 m/min, the average volume of material removed was 890 cm³ in the case of the 239 MW/cm² and 800 cm³ in the case of the 410 MW/cm² textured tool and 940 cm³ for the micro-blasted commercial one.

With the cutting speed of 250 m/min the average volume of material removed was 560 cm³ in the case of the 239 MW/cm² and 470 cm³ in the case of the 410 MW/cm² textured tool and 450 cm³ for the micro-blasted commercial one. Also for this cutting speed the variance equality and means equality statistical tests showed that the conventional tool life, if compared with the lasered ones, is practically the same.

3.3 Forging

Forging experiments were carried out under conventional industrial conditions to evaluate the lifetime of the dies after laser texturing in comparison with conventional dies. A large number of process variables where analysed but the laser intensity that produced the best results was 1.57 GW/cm^2. Figure 3 shows the tools lifetime as a function of a given treatment. Conventional and nitrided dies last for about 40’000 cycles before failure. On the other hand, the laser textured dies stands for about 125’000 cycles, which represents more than three-times improvement on lifetime.

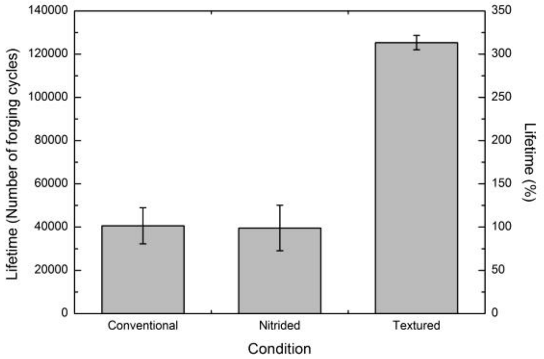

Fig. 3: *Lifetime comparisons between conventional, nitrided and laser textured dies.*

3.4 Discussion

The modified topography obtained after laser surface texturing has beneficial effects on the tools lifetime. In particular, it was observed at the tools surface after testing that the coatings become more bonded to the substrate [8 - 11]. At the end of life, only isolated island of tool material were detached in the case of the textured drills and inserts, in comparison to large areas in conventional tools.

Approximately the same is observed in forging tools, but the relief is composed by radial cracks. When a crack reaches a cavity produced by the laser shot, it was obligated to change direction. This leads to a shortened crack length when compared to the conventional dies. It seems that this effect has a major impact on the dies lifetime.

Flank wear in conventional drills are much larger than in textured ones [8 - 11]. Additionally much adhered material is verified on the worn out tool (without coating). It was considered that the rapid growth of a built-up cutting edge in drills was the cause of breakage at 27.5 and 33 m/min cutting speeds. The adhered volume is greatly reduced on the textured areas even when the coating was not present. This could be associated to a wavy topography, which is particularly difficult to be bonded.

For cemented carbide inserts, the laser surface textured method offers approximately the same results in terms of lifetime compared to the well-known sand blasting method. However, the laser system could be advantageous in terms of automation of the process and minimization of environmental impact.

The studies are now facing the challenges of extreme conditions such as sliding surface for satellites and drilling tools for petroleum industries.

4 Conclusions

Laser texturing could be a useful way to prepare surfaces before coating in terms of performance and lifetime of tools. The advantages on productivity in the case of the high-speed steel drills and forging dies are evident. The laser-textured drills have a life expectation ten times greater than conventional ones when drilling at 33 m/min. The laser textured forging dies last three times more than conventional or nitrided ones under industrial service. However, in the case of face milling with cemented carbide inserts, the lasered tools have the same lifetime of micro-sand blasted ones. The laser technique also looks toward waste minimization and manufacturing processes sustainability. The preliminary results are encouraging and may serve as starting point for further investigations and innovations on key industrial sectors, such as aerospace and petroleum.

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