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Laser texturing of substrate of coated tools — Performance during machining and in adhesion tests

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ABSTRACT

In machining, a laser beam with a high density of energy can be used to promote nano- or microstructural surface changes of the substrate of the tools with the goal of improving the adhesion of the coatings. The detachment and fragmentation of coatings during machining will compromise tool performance by the premature exposition of the substrate and may cause wear by fragments of hard and abrasive particles. The goal of this study is to test this new technology of laser texturing of cemented carbide inserts of ISO K grade before coating them with TiAlN and AlCrN. The performance of these laser-textured tools was compared with that of microblasted tools (the commercial technique normally used). Tool life tests in face milling of compacted graphite cast iron (CGI, grade 450) were carried out and the adhesion of the coated layers to the substrates of the tools was characterized by Rockwell indentation tests and scratch tests with a progressive load. The tool life results showed that the laser-textured tools outperformed the microblasted commercial cutting tools under the conditions tested. The adhesion results measured by scratch and Rockwell indentation tests showed greater delamination of the microblasted tools than of the laser-textured tools.

1. Introduction

In general, ceramic coatings composed of carbides or nitrides of transition metals, such as TiC, TiN, TiCN, and TiAlN, provide wear protection, resistance to heat and corrosion, and good adhesion to the substrate, exhibit high hardness, and are applied on mechanical components and cutting tools [1].

Due to the wide industrial applicability of coatings, there is a growing need to understand the fundamental properties of these hard films and how they protect a surface. The study of coatings has a multidisciplinary aspect as it involves knowledge of their chemical, physical, and tribological properties [2]. The difference in performance of coated and uncoated cutting tools is the result of the interaction between these properties, which probably modifies the chip–tool interface region, improving the performance of the coated tool. In order to understand how coatings modify the performance of cutting tools, it is important that the coatings be analysed in machining tests as well as in tests to characterize their properties, morphology, microstructure, and especially their adhesiveness to the substrate.

The performance of a coating deposited on the surface of a tool supporting constant changes in mechanical and thermal stresses of the machining process depends, above all, on a good adhesion of the film on the substrate. Good adhesion of the coating is very important because a tool with a coating with insufficient adhesion can behave worse than one without coating. The formation of hard and abrasive particles resulting from the premature destruction of the coating accelerates the wear of the surfaces that are in contact [3], hence the importance of having available new deposition processes, better control of the deposition process, better control of sources of supply of materials constituting the coating, substrate materials with properties which provide less variance with the coating properties, and techniques which can physically modify the substrate without significantly altering its mechanical properties to improve the adhesion at the substrate–coating interface.

The development of tool substrates with properties compatible with the coating properties can be a good alternative for improving the adhesion of the coating to the substrate. But attention should be paid, for example, to the fact that a higher hardness of the substrate in order to approximate to the hardness of the coating, thus obtaining a minor discrepancy between these properties, can cause an undesirable effect on the substrate, reducing its toughness [4]. This is particularly important for tools used in intermittent cutting, which suffer constantly from impacts upon entry to and exit from the workpiece.

A good option to approximate the properties of the tool substrate and the coating without affecting the toughness of the tool is to modify

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the properties of the substrate only in regions near the interface with the coating [5]. They are also known as Functionally Graded Materials (FGMs), where a two-phase material presents a smooth variation in the volume fraction of the second phase along its thickness, ensuring a gradual variation in its microstructure and consequently in its properties [6,7].

In recent years, laser texturing has emerged as a competitive option for the production of holes and surface texture modification of components [8]. Examples in the aircraft industry are turbine components (blades) and combustion chambers [9]. In microtechnology, the problems of permanent lubrication of miniaturized components, due to the minimal amount of lubricant and the difficulty of confining it to the surfaces in contact, are a challenge [10,11].

In machining processes, laser texturing is used to improve the adhesion properties of hard coatings on the surfaces of cutting tools. In the process of laser texturing, a laser with short pulses and a high repetition rate causes texturing from the formation of liquid pools. After solidification of these pools, the formation of nanostructures occurs, allowing a better anchoring of the coating. The interaction of the laser with the material is influenced by factors such as the nature of the substrate, the composition and structure of the surface, the energy, frequency, and pulse width of the laser, and interaction with the atmosphere. In this process, cleaning and texturing of the substrate can occur simultaneously, and the material receives an amount of additional energy that causes it to remelt superficially. Macroscopically, the surface roughness increases, generally due to the formation of craters originated from the melting and ablation of the material [3], which can probably contribute to increasing the adhesion of the coating.

The technique of modifying the texture of the substrate of cutting tools through laser beams in order to improve the adhesion of coatings is relatively new to machining and still lacks many investigations since there are few published studies, even though their number has increased in recent years [12–15]. Its potential shows that it is a very promising alternative to improve the adhesion of coatings on cutting tools.

Reduced tool wear of TiAlN-coated tools was achieved with a periodical shallow stripe-grooved surface (produced by femtosecond laser technology) parallel to the cutting edge (5 μm deep, 20 μm wide, and 20 μm apart) and applied in the process of face milling AISI 1053 steel [12]. They successfully produced this shallow texture for machining steel after testing tools with a deeper grooved surface (100–150 μm deep and 700 μm apart) that had successfully machined aluminium alloys. In more resistant materials, shallower groves guarantee higher integrity of the texture. Further development of the application of this technology to machining was presented by the same research group [13]. In this study they textured both the rake and the flank surface of the tools and applied them during face milling of AISI 1053 steel. Crater wear was reduced because the texture served as a reservoir for cutting fluid and debris and the micro-stripe grooved flank surface drastically diminished the flank wear.

Neves et al. [14] carried out laser texturing of cemented carbide tools prior to PVD coating of TiAlN and used them in turning of AISI 1045 steel. Better tool lives were achieved with the laser-textured tools as compared to commercial ones. They attributed this superior performance to a better adhesiveness of the coating on the substrate of the tools, measured by Rockwell indentation.

Another successful application of laser-textured tools was achieved in machining hardened steel by Zhang et al. [15]. After texturing, the tools were coated with TiAlN. In this case the TiAlN coatings were able to contour the V type of groove and also served as cutting-fluid reservoirs. The modified rake surface of the tools reduced the cutting forces, the coefficient of friction between tool and chip, surface roughness and wear compared to conventional tools. In dry cutting, the results were also positive but not better than when using cutting fluids.

Other authors have also studied the effect of laser texturing on the surface of components, not only in machining tools but also in forming tools or surfaces that will experience friction. Shum et al. [16] showed improvements in the wear resistance and friction coefficient of diamond-like carbon (DLC) coatings on laser textured surfaces. Segu et al. [17] produced grooves (combinations of circles and ellipses) on surface discs made of AISI 52100 steel with Nd:YAG laser equipment. Pins were also textured and frictional unidirectional pin-on-disc tests on the lubricant regime revealed a considerable reduction in the friction coefficient for the dimpled surfaces as compared to untextured surfaces. Greater benefits were obtained for deeper dimples and higher sliding speeds.

Thus, the main justification for this work is to contribute to further research and to provide data which will give more technical support to the viability of using this new technology. The work aims to evaluate the performance of laser-textured coated carbide tools compared to commercial coated tools with substrates textured by microblasting through tool-life tests in face milling of compacted graphite cast iron (CGI). Characterization tests such as variable depth scratch tests and Rockwell indentation tests were also performed in order to verify the coating adhesiveness and to explain the results of the machining tests.

2. Experimental procedures

2.1. Materials and equipments

The tools used in the tests were SEMN 12 04 AZ 235-H13A cemented carbide inserts. These tools were mounted onto an R260.22-080-15063022 milling cutter with a diameter of 80 mm and capacity for six inserts. They were both manufactured by Sandvik Coromant. In order to save workpiece material, only one insert was clamped into the milling cutter for the tool-life tests. Although a slight difference can occur if compared to a fully loaded milling cutter [18], this configuration will not interfere with the tool-life results because all the tests used only one insert and the feed per tooth was kept the same.

The machining tests were carried out in a Discovery 760 model CNC machining centre, manufactured by Industrias Romi S.A., with a variable spindle speed from 10 to 10,000 rpm and 9 kW of power. The maximum flank wear was controlled with the help of an Olympus SZ61 optical microscope equipped with an Evolution LC model colour CCD camera and Image Pro image analysis software.

The workpiece material was CGI 450 manufactured by Tupy S.A. with an average hardness of 237 HB and a predominantly perlitic matrix with approximately 2% ferrite. The graphite showed a count of 218 particles per millimetre squared, most of them vermicular, with 7% having a nodular shape. The test samples have the shape and dimensions shown in Fig. 1. This shape guarantees the production of a homogeneous microstructure throughout its cross-section. Four holes were drilled in the bottom to fix it onto the table of the machine centre.

A homemade progressive load scratch tester and a Rockwell indenter were used to check the adhesiveness of the tool coatings. The scratch tester was developed by the Laboratory of Tribology and Materials — LTM of the School of Mechanical Engineering of Federal University of Uberlândia, Uberlândia/MG, Brazil and is shown in Fig. 2. Load and displacement can be monitored during tests with this equipment. The Rockwell indentation tests were carried out in a Wolpert Universal hardness tester.

Forty eight (48) inserts were divided into two groups of twenty-four (24) tools, and each group underwent one type of texturing. The first group was texturized in normal commercial form, where the whole tool was subjected to microblasting with hard particles of SiO_2 in order to remove the cobalt from the surface of the insert, improving the adhesion of the coating that was subsequently deposited. The microblasting with hard SiO_2 particles creates an uncontrolled texture at the surface of the insert as illustrated in Fig. 3(a) and (b), which helps anchor the coating.

The other batch of tools was laser texturized. This texture was produced using a CuHBr (copper hydride and bromine) laser beam