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Laser surface texturing of a WC-CoNi cemented carbide grade: Surface topography design for honing application

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ABSTRACT

Abrasive effectiveness of composite-like honing stones is related to the intrinsic surface topography resulting from the cubic boron nitride (CBN) grains protruding out of the metallic matrix. Within this framework, Laser Surface Texturing (LST) is implemented for replicating topographic features of a honing stone in a WC-base cemented carbide grade, commonly employed for making tools. In doing so, regular arrays of hexagonal pyramids (similar to CBN grains) are sculpted by a laser micromachining system. Micrometric precision is attained and surface integrity does not get affected by such surface modification. Finally, potential of laser-patterned cemented carbide tools, as alternative to conventional honing stones, is supported by successful material removal and enhanced surface smoothness of a steel workpiece in the abrasive testing.

1. Introduction

Honing stones employed for precision machining applications are usually fabricated from composites consisting of cubic boron nitride particles, acting as super hard abrasives, embedded in a metallic matrix. In general, the abrasive effectiveness of honing stones is directly related to the intrinsic surface topography resulting from the super hard grains protruding out of the matrix (e.g. Ref. [1]). In this regard, the use of more conventional hard materials may be proposed for this tooling application, as far as the surface topography features of current honing stones could be replicated at the corresponding length scales. Considering that cemented carbides may be an interesting option, potential success of this approach will widen out the range of properties of honing tools, as a direct function of the quite variable range of microstructural assemblages existing for these materials [2]. Surface texturing of structural materials usually yields improved functional performance, significant life extension and even wider application opportunities [3,4]. Within this context, special attention has been paid to tribological application of textured surfaces, particularly aiming for reduction of friction between contact surfaces [5–7]. For instance, geometrical properties of grooves have been found to exhibit a strong impact on the lubricant distribution of piston rings [8].

Laser surface texturing (LST) using ultra-short pulse laser has become a popular micromachining method [9,10]. It is particularly suitable for tiny parts with high precision and short time machining requirements. During LST processing, the ultra-short pulse laser has extreme short reaction time with the target material. Thus, material is removed by cold ablation rather than by thermal reaction, i.e. melting and vaporization. As a result, thermal damage may be effectively diminished. This highlights a noticeable advantage of LST over other non-abrasive surface texturing options, e.g. electrical discharge machining (EDM), regarding surface patterning of cemented carbides [11,12].

Potential of LST as surface modification technology, especially in cemented carbides, has been reported in literature [13–17]. However, investigation about this subject is rather scarce, and mainly focused on the influence of basic LST patterning or shaping on tribological performance. In this regard, implementation of LST has shown to be beneficial for both grinding tools, as cutting edges are readily exposed, and turning ones, as supplementary tool-chip interface is created [18,19]. Furthermore, capability of laser machining to shape cutting edge roundness of cemented carbides has been recently demonstrated [20]. More complex patterns, as those associated with surface topography of honing tools, require precise movement control of laser beams. In a recent study, the authors have proven the capability of high precision 5-axis laser micromachining system, combined with a picosecond laser, to move the beams along the x-, y- and z-axis with micrometric precision [21]. Such accurate

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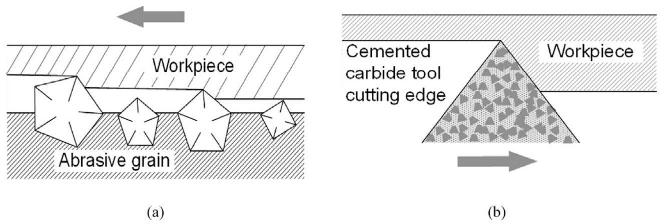

Fig. 1. Schematic illustration of material removal in (a) abrasive machining processes (where CBN composite is used as cutting tool); (b) chip-removal machining processes (where cemented carbide is used as cutting tool).

Table 1
Microstructural properties of the honing stone B151 and aimed surface topography features for the WC-CoNi cemented carbide sample.

Sample	Grain quantity	Sample surface (x10^7 μm^2)	Total grain surface area (x10^6 μm^2)	Phase ratio	Grain shape
B151	355	4.2	3.8	8.9%	Most varying from rectangle to hexagon
WC-CoNi	343	6	5	8.3%	Hexagon

movement of laser beams, especially their oscillation in the perpendicular direction to the workpiece, facilitates the production of complex surface structures. Such technical development can not only widen the application range of LST but also open windows for creative surface topography design. An example of successful application of this approach is found on enhanced abrasive ability and/or lubrication efficiency of grinding wheels by means of manufactured surface topography, in terms of either micro-texturing or defined ceramic grain patterns [22–24].

In this study, LST is employed to reproduce the surface topography of a conventional honing stone on the surface of a WC-CoNi cemented carbide grade. It was programmed to induce simultaneous movement along the x-, y-, z-axis of the laser beams, such to remove very tiny volumes of the cemented carbide (workpiece) and sculpt grain-like pyramids from the surface. Once aimed surface topography was shaped, geometrical features of LST surface were measured and resulting surface integrity was assessed. Finally, performance of a cemented carbide tool with the LST textured surface was tested in a workbench designed to simulate an external honing (cutting) process.

2. Novel cemented carbide tool conception

2.1. Fundamental ideas

Although CBN composites and cemented carbides are commonly employed for fabricating cutting tools, their effective implementation depends on cutting conditions and requirements. CBN composites are more appropriated for non-conventional abrasive machining processes, such as grinding and honing. Here, workpiece material is removed by a multitude of tiny cutting edges formed by the protruding grains, with size ranging from 2 to 250 µm (Fig. 1(a)) [25]. On the other hand, cemented carbides are usually employed in chip-removal machining processes, such as turning and milling. Under these conditions, workpiece material is removed rather by one cutting edge in connection with different feeding movements. The cutting edge is then composed of several (many) carbide grains, with size ranging from 0.5 to 30 µm, and should be shaped prior to the application as cutting tool (Fig. 1(b)).

A critical step of this study was to replicate the surface topography of reference honing tool (associated with exposed abrasive grains) on the cemented carbide surface by means of LST. This effectively means shaping tiny cutting edges at the cemented carbide surfaces (Fig. 2(a)). Considering that size difference of abrasive particles for conventional honing tools and the studied cemented carbide grade may be as large as 10 times (Fig. 2(b)), the implemented approach here was to sculpture pyramids (similar to CBN grains) out of the cemented carbide's surface by means of high precision LST. The formed cutting edges should possess similar geometrical features as CBN grains, aiming to endow a surface topography with similar cutting ability as the one exhibited by CBN composites (Fig. 2(c)).

2.2. Design of geometrical features for surface topography of the new tool

In a recent work, authors have provided a detailed quantitative characterization of surface topography of a conventional honing stone, tagged as B151, which will be used here as reference condition [26]. It was done following an experimental protocol consisting of five steps: specimen preparation, surface scanning, image assembly, image digital processing and final surface quantification. It also involved the use of laser scanning microscopy (LSM) and digital imaging processing for assessing significant dimensional, geometrical and positional properties of CBN grains at the surface of B151 honing stone. Measured properties are listed in Table 1. Taking into account the microstructural assemblage of the reference honing tool, aimed surface topography for being

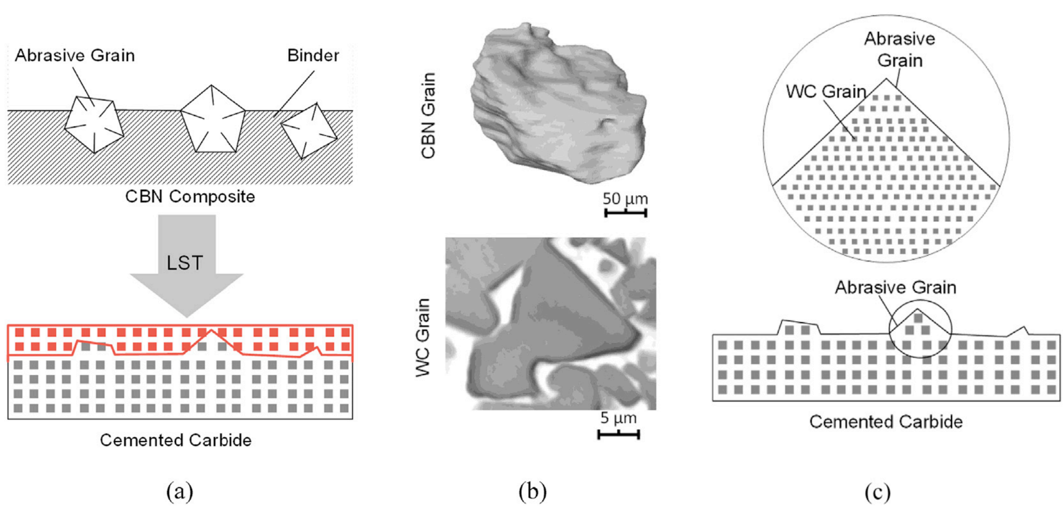

Fig. 2. (a) Schematic illustration of novel tool fabrication concept for honing processes; (b) grain size comparison between CBN grain and WC grain of the studied materials; (c) fabrication of abrasive grain with WC grains.