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Procedia CIRP 42 (2016) 439 – 443

www.elsevier.com/locate/procedia

18th CIRP Conference on Electro Physical and Chemical Machining (ISEM XVIII)

Tribological Performance of Laser Patterned Cemented Tungsten Carbide Parts

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Abstract

Some tools for machining processes used to be guided by supporting parts while using them for cutting or abrasive machining. For instance, the guide stone is used as supporting part in the honing process, which maintains the concentricity of the rotating axis. The contact surfaces of the supporting parts should exhibit the following properties: adequate combination of hardness, toughness and wear resistance. The damage of contact surfaces can be caused by a combination of friction and adhesion, related to the weakness of surface conditions in the tribological system, e.g. asperities, debris and pores. In order to investigate the impact of the surface topography, contact surfaces of the supporting parts made of cemented tungsten carbide (WC-Co) have been treated by means of laser surface patterning (LSP). Two different surface patterns with deterministic geometries on the micro and nano scale are achieved by two distinct LSP methods: line-like patterns by Laser-Interference Metallurgy (LIMET) with ns-laser and dimples by ps-laser. Tangential force coefficients, similar to the coefficient of friction (COF) in the non-abrasive case, are measured to evaluate the impact of the surface patterns. In this paper, the LSP methods as well as the analysis of the resulting surface topography are introduced. It is found that higher friction is obtained by line-like patterns whereas dimples can efficiently reduce the friction. At low load, hydrodynamic effects are reinforced as the dimples work as lubricant reservoirs and trap wear particles, and the observation becomes less obvious at high load. Meanwhile, only slight friction augmentation is observed by line-like patterns when the load increases.

Peer-review under responsibility of the organizing committee of 18th CIRP Conference on Electro Physical and Chemical Machining (ISEM XVIII)

Keywords: Laser Surface Patterning; Tribology; Cemented Tungsten Carbid (WC-Co); Abrasive Machining Processes; Surface Integrity

1. Introduction

Since the 1960s, it has been attempted to modify the surface topography to improve the tribological performance of the contact surfaces by several machining techniques, especially to reduce the friction and improve wear resistance [1]. Cemented tungsten carbide (WC-Co) is widely used as cutting tools and supporting parts in industry. Excessive friction between the contact surfaces always produces abundant heat and diminishes the part lifecycle. It appears to be significant to minimize the friction by surface treatment. However, WC-Co is difficult to be machined by traditional shaping methods due to its hardness. Various surface treatment methods for hardmetal, such as Electrical Discharge Machining (EDM) have been employed to machine the surfaces on the micro scale. The accuracy of these methods is fairly high compared with the traditional chip-removal method [2].

During the EDM process, a great number of tiny materials are removed individually due to the electrical discharges between the two electrodes, which finally result in a homogenous material removal. However, some defects also can be induced in the affected zone, such as pores, impurities and fractures due to thermal effects. Furthermore, these

Peer-review under responsibility of the organizing committee of 18th CIRP Conference on Electro Physical and Chemical Machining (ISEM XVIII)
doi:10.1016/j.procir.2016.02.228

methods lead to non-uniform residual stresses in the surfaces [3, 4].

Compared with EDM, laser surface patterning (LSP) is a high precision surface treatment technique, which makes use of the laser pulses with adjustable energy density and pulse repetition frequency (PRF) to machine the surfaces. LSP possesses many advantages, e.g. clean, precise and short processing time. The ablation rate and precision of LSP are strongly influenced by the pulse duration, PRF, energy density and laser wavelength [5]. Due to the high intensity, melting, recrystallization, phase transformation etc., can occur on the micro and nano scale. Thermal effects can be efficiently reduced when the pulse duration is shortened, e.g. ps-pulses have less thermal impact than ns-pulses of identical fluence. Due to less thermal effects, ps-laser results in less surface damage [6, 7].

Laser-Interference Metallurgy (LIMET) is a process, where two or three pulsed laser beams with the same PRF are superimposed on the target surface [8, 9]. By means of LIMET, it is possible to produce periodic surface patterns with dimensions on the sub sub-micron level up to micrometers, depending on the angle between the interfering beams and the thermophysical properties of the materials involved.

It is the objective of this study to introduce the fabrication methods of two different patterns with defined geometries on WC-Co surfaces by means of LSP. Surface integrity is characterized in terms of geometry. The first results related to the tribological performances will be presented.

2. Experiments

2.1. Material properties

The WC-Co hardmetal (Table 1) is selected as test sample. This hardmetal has a grain size of 20 µm and contains 14% Cobalt and 14% Nickel as binder. The hardness of the hardmetal is 610HV30, i.e. it is a relatively soft hardmetal.

Table 1. WC-Co hardmetal properties.

Material	WC-Grain Size (µm)	Co (%)	Ni (%)	Density (g/cm³)	Hardness (HV30)
VN77	20	14	14	12.82	610

2.2. LSP characteristics

The mechanism of laser-matter interaction is mainly determined by the pulse duration. When the laser pulse duration is in the range of 10 ps and below, the pulse duration is usually shorter than the heat diffusion time. Therefore, the deposited heat cannot move away and there is only a local temperature rise resulting in material phase transformations (melting and vaporisation) [10]. The difference of the Co and WC melting points denote the thermal behaviour of Co from WC in this regime. It is known that the energy intensity (fluence) less than 2.5 J/cm² is suitable to only remove Co [11]. In this case, WC grains easily break out due to melting and vaporizing of the Co glue. Two different surface patterns are produced by two types of laser installations: LIMET with ns-laser and ps-laser.

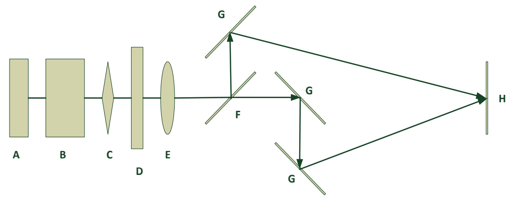
2.2.1. Line-like patterns by ns-laser

The used ns-laser is a solid state Nd: YAG source (Spectra Physics Quanta Ray Pro 290). The laser beams have a PRF of 10Hz, wavelength of 355nm, pulse duration of 10ns and fluence of 2.3 J/cm² at the machining zone (Table 2).

Table 2. Basic information of the ns-laser setup.

Laser type	Laser source	Pulse duration (ns)	Wave length (nm)	PRF (Hz)	Fluence (J/cm²)
ns-laser	Nd: YAG	10	355	10	2.3

Special configurations of the laser beam trajectories are necessary to obtain the line-like pattern with defined geometry in LIMET. Fig. 1 shows the trajectory of the laser beams: they are produced by the Nd: YAG laser source, focused by a lens, then split equally by a beam splitter. The sub-beams are reflected by the mirrors respectively and finally interfered on the target surface.



A: Laser source	C: Power meter	E:Lens	G:Mirror
B: Attenuator	D: Shutter	F:Beam splitter	H:Sample

Fig. 1. LIMET experimental setup

The superposition of the two sub-beams leads to interference resulting in a line-like pattern. Two parameters are used to describe the pattern geometry: periodicity, defined as the distance between two adjacent peaks or valleys, and height, defined as the distance between the peak and its adjacent valley. The periodicity is defined by the trajectory of the laser beams and can be obtained by Equation (1) [8]:

$$P = \frac{\lambda}{2\sin\left(\frac{\theta}{2}\right)} \quad (1)$$

λ: Laser wavelength
θ: Angle between two sub-beams
P: Calculated periodicity

Table 3 shows the experimental parameters of the ns-laser setup. Based on the listed parameters, the periodicity is calculated to be 11.3 µm. The removed material volume is mainly dependent on the absorption of the laser beam energy [5]. It means that the depth of the line-like pattern depends on the pulse energy and pulse number. The correlation between the removed material volume and the absorbed energy is not discussed in this paper.