IOP Conf. Series: Materials Science and Engineering **258** (2017) 012006 doi:10.1088/1757-899X/258/1/012006

Frictional Performance Assessment of Cemented Carbide Surfaces Textured by Laser

S Fang[1,2,3], L Llanes[1,2,*], S Klein[3], C Gachot[4], A Rosenkranz[4], D Bähre[3], F Mücklich[4]

[1]CIEFMA – Dept. Materials Science and Engineering, Universitat Politècnica de Catalunya, EEBE-Campus Diagonal Besòs, 08019 Barcelona, Spain
[2]Barcelona Research Center in Multiscale Science and Engineering, Universitat Politècnica de Catalunya, 08019 Barcelona, Spain
[3]Institute of Production Engineering, Saarland University, Saarbrücken, 66123 Germany
[4]Chair of Functional Materials, Saarland University, Saarbrücken, 66123, Germany

* luis.miguel.llanes@upc.edu

Abstract. Cemented carbides are advanced engineering materials often used in industry for manufacturing cutting tools or supporting parts in tribological system. In order to improve service life, special attention has been paid to change surface conditions by means of different methods, since surface modification can be beneficial to reduce the friction between the contact surfaces as well as to avoid unintended damage. Laser surface texturing is one of the newly developed surface modification methods. It has been successfully introduced to fabricate some basic patterns on cemented carbide surfaces. In this work, Direct Laser Interference Patterning Technique (DLIP) is implemented to produce special line-like patterns on a cobalt (Co) and nickel (Ni) based cemented tungsten carbide grade. It is proven that the laser-produced patterns have high geometrical precision and quality stability. Furthermore, tribology testing using a nano-tribometer unit shows that friction is reduced by the line-like patterns, as compared to the polished one, under both lubricated and dry testing regimes, and the reduction is more pronounced in the latter case.

Key words: Cemented carbide; Laser Surface Texturing (LST); Direct Laser Interference Patterning Technique (DLIP); Tribology; Friction.

1. Introduction

Cemented tungsten carbide hardmetal is made of tungsten carbide powder (WC) with metallic powder by sintering under high pressure and temperature. Due to its high hardness and suitable toughness, hardmetals are often used as cutting and forming tool materials (e.g. Ref. [1]). Electrical Discharge Machining (EDM) is one of the most advanced hardmetal processing technologies applied in the industry. EDM is capable to shape the material with relatively precise dimensions, but some thermal defects can be induced such as pores and re-disposition [2-5]. Therefore, it is difficult to obtain the

desired surface structure with higher accuracy using this method. Laser surface texturing (LST) has a wide range of application as an approach of surface modification. It can be an alternative technique to ablate the hardmetals and to modify their surface structure with accuracy in micrometer (μm) scale.
In the LST family, Direct Laser Interference Patterning Technique (DLIP) is a metallurgical process that uses a superposition of two or three pulsed laser beams with the same frequency [6,7]. The laser beam ablation is mainly dependent on three factors: wavelength, energy density and duration of pulses. The wavelength of the laser beams has crucial impact on the energy absorption. In general, for metals and ceramics the absorption is higher with shorter waves. The absorption in the case of the cobalt based cemented tungsten carbide is for example 85% at 355 nm [8]. The ablation rate of the laser beams is related to the energy density and the pulse duration decides the mechanism of laser-matter reaction [7]. The incident laser beam generates an electric field, which excites the electrons, and the energy is then transmitted to the electrons by acceleration. The electrons collapse the lattice and transfer the energy to the atoms. The vibration of lattice causes the material heating and phase transformation. The energy transfer needs about 1ps for metals and slightly more for ceramics [9]. Therefore, for the ns-laser, the energy transfer takes place mostly through melting and vaporization [10]. Due to the high intensity, energy transformation of the laser beams to the material surface, i.e. melting, recrystallization, phase transformation etc., occurs in the scale of micro-/nanometer. Therefore, the surfaces generated by laser always exhibit clean and precise.
It is indicated that some basic patterns are produced on the hardmetal surface such as dimples and grooves [8,11,12]. However, there is not enough research work available dealing with the surface modification of hardmetals for tribological applications. Therefore, the work described the production of specific line-like patterns on cemented carbide by means of DLIP and the influence of the patterns on frictional performances is assessed on a nano-tribometer.

2. Materials & Experimental Procedure

2.1. Materials

A Cobalt Cemented Tungsten Carbide grade, in which the embedded WC grains have an average size of 20 μm and the binder (Co+Ni) has a nominal amount of 28 wt. %, has been selected as test samples. The microstructural characteristics of the selected material are displayed in Table 1. All the test samples should be fine polished prior to the laser treatment. After the polishing, the microstructure of the hardmetal is exposed. It is observed that the grains are randomly distributed and some damage is caused by polishing such as cracks or holes, but they can be ignored (Figure 1).

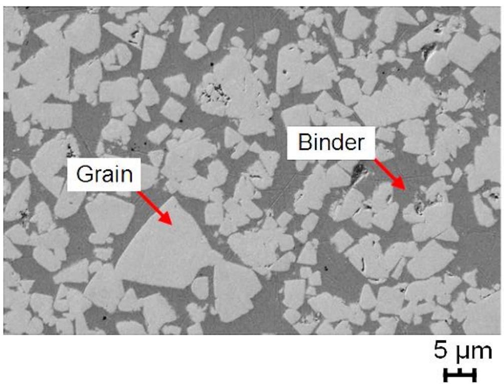


Figure 1. Polished WC-CoNi hardmetal surface, characterized by scanning electron microscopy (SEM)

Table 1. Microstructural characteristics and properties of the used WC-CoNi hardmetal.

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

2.2. Experimental Parameters

A special laser trajectory is constructed to create the interference patterns (Figure 2(a)). The laser beam is split into two sub-beams, which are conducted by a series of mirrors and converged at the focus point, where the beams produce the interference phenomena. The line-like structures are produced when these phenomena occurs on the material surface. The information of the laser installation is shown in Table 2.

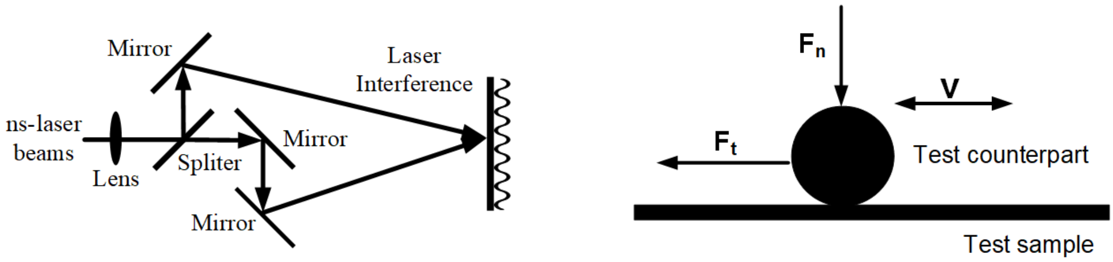
Table 2. Information and configuration of the ns-laser installation.

Laser type	Laser source	Pulse duration	Wave length (nm)	Pulse repetition frequency (Hz)	Fluence (J/cm²)	θ(°)
ns-laser	Nd: YAG	10 ns	355	10	2.3	1.8

The periodicity of the interference patterns can be calculated with Equation (1) [6,7]:

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

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



(a) (b)

Figure 2. Schematic illustration of (a) DLIP for production of laser interference structure and (b) dynamics of the nano-tribometer.

According to the configuration parameters of the ns-laser installation in Table 2 and Equation (1), the line-like patterns have the periodicity of 11.3 µm.

2.3. Frictional Tests on the Nano-tribometer

The nano-tribometer (NTR-CSM instruments) is used to measure the coefficient of friction (COF) by sliding movement between the sample and balls with or without lubricants. The normal force Fn that is applied on the ball, as well as the tangential force Ft that is produced by the linear reciprocal movement of the sample holder, are recorded during the test (Figure 2(b)). COF is then calculated in account of the two forces using Equation (2):

$$\mu = \frac{F_t}{F_n} \quad (2)$$

Friction tests have been conducted on two types of surfaces (polished surfaces and line-like patterns) with and without lubricants, for three repetitions. All the samples are tested under identical conditions, as shown in Table 3. The test counterparts are made of Steel 100Cr6 and have the diameter of 3 mm. The sample is fixed on the test table and moves reciprocally at a maximal linear speed of 1 mm/s with an amplitude 0.6 mm. 1000 cycles are set to test the frictions with and without lubricants. The lubricant Kadiol 50 is used, which has a kinematic viscosity υ of 5.6 mm²/s at 40 °C. The normal load applied on test sample is 1 mN.

Table 3. Nano-tribometer configuration.

Acquisition rate (Hz)	Trajectory	½ Amplitude (mm)	Max Lin.Speed (mm/s)	Frequency (Hz)	Cycle	Normal load (mN)
100	Sinus	0.3	1	0.53	1000	1

3. Results and Discussion

3.1. Geometrical Characterization

The geometrical properties of the line-like patterns are measured and characterized by Laser Scanning Microscopy (LSM). Figure 3(a) shows the surface image taken by LSM, and some discontinuity can be observed along the line-like patterns. The discontinuity represents that the excessive melting and vaporization of the material occurred in certain places. This can be resulted from the inhomogeneous distribution of binder and grains, which have different melting and vaporization temperatures. For line-like patterns, three parameters are measured (Figure 3(b)): (1) periodicity, defined as the distance between two adjacent peaks or bottoms; (2) height, defined as the distance between the peak and its adjacent bottom; and (3) peak angle. The textured surface area is about 20 mm x 3 mm. The mean values of periodicity, height and angle, are 11.8 µm, 0.6 µm, and 7.5° respectively. A wave profile of the line-like patterns can be rebuilt by the software Origin 9 with the measurement data obtained by LSM (Figure 3(c)).

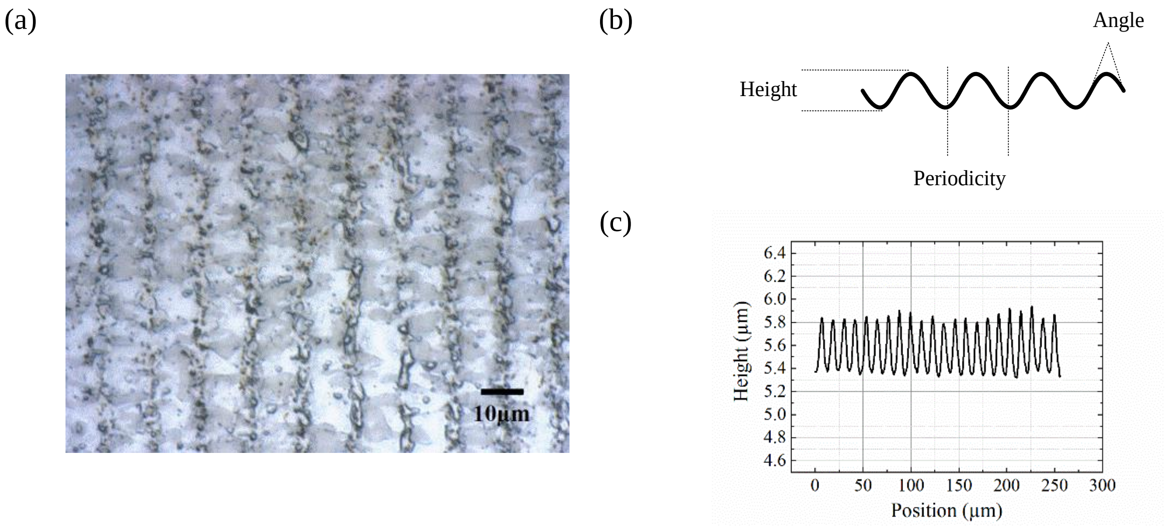
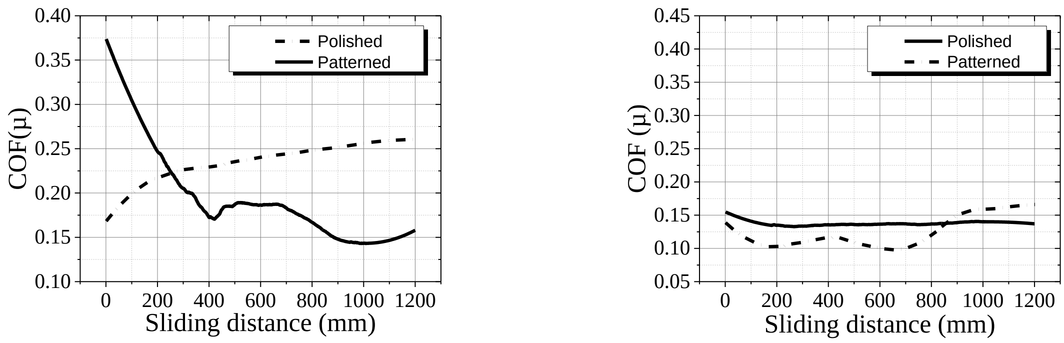


Figure 3. (a) Surface image in 2D (LSM), (b) geometrical characterization of the line-like structure, (c) wave profile of the cross section in the transversal direction.

3.2. Tribological Properties Investigation

The signals of the normal force Fn and the tangential force Ft for each test are recorded, and the real-time values of COFs of the tests are shown in figure 4, where Figure 4(a) and 4(b) show the COF comparison between polished and patterned surfaces in the cases of non-lubricant and lubricated, respectively.

Without lubricants, the frictional performances of the polished and patterned surfaces are quite unstable (Figure 4 (a)). The COF of the polished surface experienced a remarkable rise along with the sliding laps, but the COF of the patterned surface experienced a huge drop at the beginning. These can be explained by the changes of surface microstructural conditions, i.e. deformation of the surface. In the case of polished surfaces, the materials are at first compressed and deformed at the beginning, so that the stacked materials hinder the movement of the samples and cause the COF to increase. However, in the case of patterned surfaces, the surfaces are covered by the line-like structures produced by laser, which are relatively rough than the polished ones; therefore, COF is quite high at the beginning of the test. However, the patterns are deformed and even destroyed along with the sliding laps. After the unstable stage, COF of patterned surface is much lower than the one of the polished surface. The observation can be explained by the fact that the produced debris can work as tiny lubricants between the two surfaces, which may help to reduce friction.



(a) (b)

Figure 4. COF evolution as a function of sliding laps: (a) comparison between polished and patterned surfaces in the case of non-lubricant, (b) comparison between polished and patterned surfaces in the case of lubricant.

With lubricants (Figure 4 (b)), the frictional performance of both two types of surface patterns are more stable, except that COF of patterned surfaces slightly increases between 600 cycles and 800 sliding laps. It is supposed that the patterns begin to be destroyed at 600 cycles, and the contact between the two surfaces is becoming less stable till 800 cycles. Then, friction regains stability after 800 cycles, since the patterns are completely demolished and a new stable contact is re-established. The COF of polished surfaces is relatively constant during the whole test except for a slight decrease at the very beginning, so as to the patterned surface. This observation can be explained by the fact that the lubrication film stabilizes the tribological system. However, the difference of the obtained COFs between the patterned and polished surfaces is not very obvious, and it seems that the patterns don't have effective influence in the lubricated case. This observation can be explained by the fact that the discontinuity of the patterns can barely contribute additional hydrodynamic pressure to build up a thick film, which can effectively help reduce the friction in the case of lubricant.

4. Conclusion and Remarks

Despite of the machining difficulty of hardmetals, line-like patterns have been satisfactorily produced on WC-CoNi hardmetal surface by means of LST. It provides a high precision of the structural geometry. The utilization of Direct Laser Interference Patterning Technique (DLIP) allows the

creation of the line-like structure on the surface. The structure has a period of 11.8 µm, approximately close to the theoretical prediction of 11.3 µm.
In the frictional tests, it is found that patterns created on the surfaces can effectively reduce the friction compared with the polished surfaces in the non-lubricated case. However, such expectation is not observed in the lubricated case, since the discontinuity of the patterns is unfavourable to supply necessary additional hydrodynamic pressure. Moreover, the patterned surfaces seem to be not as stable as the polished ones in both cases. These observations might be related to the surface integrity and mechanical property change induced by the laser treatment. Therefore, it is advisable to introduce surface integrity assessment, such as micro-indentation, in order to validate the supposition in the future.

Acknowledgements
The work leading to this publication was supported by the German Academic Exchange Service (DAAD) with funds from the German Federal Ministry of Education and Research (BMBF) and the People Program (Marie Curie Actions) of the European Union's Seventh Framework Program (FP7/2007-2013) under REA grant agreement n° 605728 (P.R.I.M.E. – Postdoctoral Researchers International Mobility Experience). The authors are grateful for the material supplier Saar-Hartmetall und Werkzeuge GmbH. Finally, this contribution has also been partly funded by the Spanish Ministry of Economy and Competitiveness through Grant MAT2015-70780-C4-3P (MINECO/FEDER).

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