Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 45 (2016) 235 – 238

www.elsevier.com/locate/procedia

3rd CIRP Conference on Surface Integrity (CIRP CSI)

Material loading in inverse surface integrity problem solution of cemented carbide component manufacturing by surface modification

X.P. Zhu[a], F.G. Zhang[a], M.K. Lei[a,*], D.M. Guo[b]

[a] *Surface Engineering Laboratory, School of Materials Science and Engineering, Dalian University of Technology, Dalian 116024, China*

[b] *Key Laboratory for Precision and Non-traditional Machining of the Ministry of Education, Dalian University of Technology, Dalian 116024, China*

* Corresponding author. Tel.: +86-411-84707255; fax: +86-411-84706192. *E-mail address:* mklei@dlut.edu.cn

Abstract

The inverse surface integrity problem could be effectively solved if the generation of a desired surface integrity be quantitatively correlated to process parameters or process loads. Possibility of establishing such a correlation is studied by employing a surface modification technique of high-intensity pulsed ion beam with well controlled thermo-mechanical load to manufacture WC-Ni cemented carbide component with enhanced wear resistance. The multiple surface integrity parameters including phase, microstructure and composition in addition to surface microhardness should be taken into account for establishing the correlation between process loads and surface integrity, since the interactions between the surface integrity parameters determine the wear performance of surface modified cemented carbides. The different process parameters can be quantitatively distinguished by material loading, i.e. the temperature and/or stress field evolution in the surface layer of cemented carbide under the different thermo-mechanical loads, while the material loading can be further correlated to the resultant changes in surface integrity. In this way, identification of material loading enables establishing a process-independent correlation between process loads and surface integrity for solving the inverse surface integrity problem.

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on Surface Integrity (CIRP CSI)

Keywords: Surface integrity; Surface modification; High-intensity pulsed ion beam; Material loading; High performance manufacturing

1. Introduction

Surface integrity of a component are being widely recognized and concerned as a principal factor determining the functional performance of components [1-3]. However, the desired surface integrity of high performance components is still generated by an iterative process during practice in industry. The required process parameters cannot be deduced from a given desired surface integrity merely based on the iterative way by trial and error. Therefore, the inverse problem may be solved if a correlation between process parameters and surface integrity could be established. In order to solve the inverse surface integrity problem in machining processes, Brinksmeier et al. [4,5] proposed a new concept, process signature, with emphasis on establishing a process-independent correlation between process loads within the component material and resultant materials modification. It is implied that, systematic investigations are still necessary to verify the feasibility to establish a process-independent correlation linking process parameters to surface integrity. It is revealed in our recent study that, the various parameters of surface integrity such as surface morphology, chemical composition, roughness, phase structure, residual stress, microhardness etc. should have a combined effect on the final component performance [6,7]. Consequently, the interactions between the multiple surface integrity parameters should be taken into account for the correlation to be established between process loads and surface integrity.

Generation of a surface integrity with controllable multiple surface integrity parameters is indispensable for achieving a desired high performance of components, which also facilitates the investigation to establish a process-independent correlation between the process loads and the surface integrity thus generated. It is demonstrated that surface modification techniques can be considered as an effective manufacturing approach by which the controlled multiple surface integrity parameters with active interactions are achievable according to desired high performance, from well-defined external

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on Surface Integrity (CIRP CSI)
doi:10.1016/j.procir.2016.02.350

process loads of thermal, mechanical, chemical or a combination of them in the surface layer of manufactured component, as reducing the geometrical, physical and chemical constraints from base material [7,8].

In this work, the surface modification technique based on high-intensity pulsed ion beam (HIPIB) is employed with controlled external process load of thermo-mechanical nature, termed ion beam shock processing (IBSP), for manufacturing cemented carbide components with improved wear performance. A particular case study is presented for surface integrity parameter change with an identical enhancement in surface microhardness of the cemented carbides, achieved by controlling different process parameters. Under the controllably different process parameters, the material loading and its variation in the components can be readily confirmed and compared. The material loading, i.e. the temperature and/or stress field evolution in the surface layer of cemented carbide under the thermo-mechanical load, thus can be explored to interpret multiple surface integrity parameters generation, leading to different wear performance. Identifying of material loading is discussed and considered as an effective way to correlate the surface integrity change of not only hardness alternations but also phase transformation, composition and microstructure variations etc., to the process parameters, for high performance manufacturing toward desired surface integrity.

2. Experimental

The IBSP surface modification of WC-Ni cemented carbide with bulk composition of 87 wt.% WC and 13 wt.% Ni and average WC grain size of 2 μm was carried out in TEMP-6 HIPIB equipment. The detailed description of this equipment and controlling of ion beam parameters have been reported previously [9,10]. The IBSP process parameters in this study are as follows: ion beam composition of 30% C ions and 70% proton, ion accelerating voltage of 300 kV, ion current density of 50-300 A/cm^2 with 70 ns pulse width (FWHM), irradiation of 1-10 shots. Due to the short pulse duration in the tens nanoseconds range, an energy density of 1-6 J/cm^2 per shot can be delivered adiabatically into the surface layer of a few micrometers in depth. The thin surface layer of material is thus rapidly heated, remelted and/or ablated followed by a rapid cooling due to thermal conduction into substrate, with ultra-fast heating and cooling rates typical of 10^8-10^{11} K/s. The recoil impulse due to ablation of a thin top layer typically of hundreds nm depth and generation of thermal shock in the heat affected zone can lead to strong compressive stress that may further develop to a shock wave propagating inwards. The coupled thermal-mechanical load from the IBSP result in a shock hardening layer in depth typically of several hundreds micrometers for metallic materials along with amorphous and/or nanostructure, submicron nonequilibrium microstructures in the heat affected top layer of a few micrometers. During the process, the thermo-mechanical load is well controlled by the energy input practically by adjusting the ion current density while fixing the other parameters [11,12].

For wear performance evaluation, a series of block samples were prepared by electrical wire machining, followed by ground using diamond abrasive powders and SiC abrasive paper. The polished surfaces were then treated by IBSP. The wear tests were carried out on a MM200 block-on-ring tribometer under dry sliding condition. The block WC-Ni samples were fixed and pressed under normal load of 98 N contacting with a rotating GCr15 bearing steel ring with 45 mm outer diameter and 10 mm in width at a constant sliding speed of 0.47 m/s up to 2100 s. The wear performance of WC-Ni cemented carbides was evaluated by specific wear rate, i.e., the wear volume loss of the cemented carbide block with respect to the normal load and the sliding distance. The changes in surface integrity parameters including phase transformation, chemical composition, and metallographic microstructure variations in addition to microhardness change after IBSP surface modification, was comprehensively examined concerning the material loading caused by the thermo-mechanical load.

3. Wear performance

The surface hardness, coefficient of friction and specific wear rate of cemented carbide components by the selected IBSP parameters are listed in Table 1. It is shown that, identical surface hardness of the IBSP processed WC-Ni cemented carbides can be obtained by controlling the process parameters of energy density per shot and shot number, i.e. 1 J/cm^2 and 4 J/cm^2 with 10 shots, and 6 J/cm^2 with 1 shot, respectively.

Table 1 Surface hardness, coefficient of friction (COF) and specific wear rate (SWR) of cemented carbide components by ion beam shock processing with the selected parameters by which identical surface microhardness is obtained.

Energy density (J/cm^2)	*N* Shot number	$HV_{0.2}$ (GPa)	COF	SWR $\times 10^{-7}$ $mm^3/N\ m$
0	0	11.80	0.54-0.78	11.71
1	10	14.72	0.50-0.69	8.55
4	10	14.87	0.50-0.66	4.95
6	1	14.92	0.56-0.71	8.78

It is shown that, the microhardness value of top surface increased notably from the original 11.80 GPa of base material to 14.72-14.92 GPa by the IBSP surface modification. Although the effect of surface hardening is the same, the coefficients of friction and specific wear rates differed greatly and then the optimized parameters can be selected as 4 J/cm^2 with 10 shots for processing cemented carbide mechanical seal rings to achieve a better tribological and wear performance in pump applications. A typical mechanical seal ring is presented in Fig. 1 where the outer diameter of ring is 150 mm.