Precision Engineering 33 (2009) 486–491

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

Polishing of single point diamond tool based on thermo-chemical reaction with copper

Naomichi Furushiro[a,*], Masahiro Higuchi[a], Tomomi Yamaguchi[a], Shoichi Shimada[b], Kazushi Obata[c]

[a] Kansai University, 3-3-35 Yamate-cho, Suita, Osaka 564-8680, Japan
[b] Osaka Electro-Communication University, 18-8 Hatsu-cho, Neyagawa, Osaka 572-8530, Japan
[c] A.L.M.T. Corp., 1-4-16, Kyomachibori, Nishi-ku, Osaka 550-0003, Japan

ARTICLE INFO

Article history:
Received 22 September 2008
Received in revised form
22 December 2008
Accepted 31 January 2009
Available online 26 March 2009

Keywords:
Thermo-chemical polishing
Diamond cutting tool
Fracture strength
Wear rate
Crack healing
Tool life

ABSTRACT

This paper describes a new polishing method for diamond cutting tools. The method is based on the principle of oxidization of copper and deoxidization of copper oxide by carbon. A diamond tool was brought into contact with a copper plate, heated in air to a range of 323–523 K. The depth of the removed layer of diamond increased almost linearly with contact time and reached approximately 7 nm after 6 h. In this erosion process, pre-existing microcracks on the diamond surface were reduced. In comparison with the mechanically polished tool, the thermo-chemically polished tool was highly resistant to chipping and yielded a significant rise in tool life.

© 2009 Elsevier Inc. All rights reserved.

1. Introduction

The cutting edges of single point diamond tools are usually precisely formed by fine polishing with scaifes. Mechanical polishing, however, produces microcracks on the diamond surface because of high polishing pressure and elevated temperatures. In related research, Tanaka et al. found that these microcracks lengthened as a result of thermo-chemical erosion by oxygen at the microcrack tips, and the resultant microfractures reduced the strength of the diamond [1]. This is thought to be the source of chippings that occur on cutting edges during diamond turning processes. Hence, the elimination of microcracks is very important because chipping reduces workpiece quality and tool life.

To solve the chipping problem, novel polishing methods have been proposed, such as diffusion of carbon atoms into certain metals [2,3], sputtering-off of carbon atoms by bombardment of energized ions [4], and tribochemical polishing combining mechanical abrasion and chemical dissolution of surface atoms [5]. These methods, however, have the disadvantages of difficulty of use and high cost. Thus, a simpler polishing method, based on the thermo-chemical reaction of the carbon in a diamond with copper, is proposed and discussed in this paper.

2. Principle of thermo-chemical polishing

Tanaka et al. stated that some thermo-chemical reactions between a diamond tool and a work material cause tool wear [6]. The mechanisms of tool wear are classified into three types, i.e., graphitization, oxidization–deoxidization reaction, and carbonization. This information gives us helpful suggestions how to polish diamond tools. The graphitization of diamond and carbide formation between the diamond and work material are not applicable to the polishing of diamonds, but it seems quite possible to polish a diamond based on the principle of oxidization of the work material and deoxidization of the oxidized work material by the diamond. Therefore, the oxide formation of copper and carbon was considered based on thermodynamics and the equilibrium state of chemical reaction systems.

It is well known that chemical reactions between C and O_2 occur as follows: $C + O_2 \rightarrow CO_2$ and $2C + O_2 \rightarrow 2CO$. In addition, reactions between Cu and O_2 occur according to the equations: $2Cu + O_2 \rightarrow 2CuO$ and $4Cu + O_2 \rightarrow 2Cu_2O$. These oxidation reactions

* Corresponding author at: Department of Mechanical Engineering, Kansai University, 3-3-35 Yamate-cho, Suita, Osaka 564-8680, Japan. Tel.: +81 6 6368 1121; fax: +81 6 6388 8785.
E-mail address: furusiro@ipcku.kansai-u.ac.jp (N. Furushiro).

0141-6359/$ – see front matter © 2009 Elsevier Inc. All rights reserved.
doi:10.1016/j.precisioneng.2009.01.004

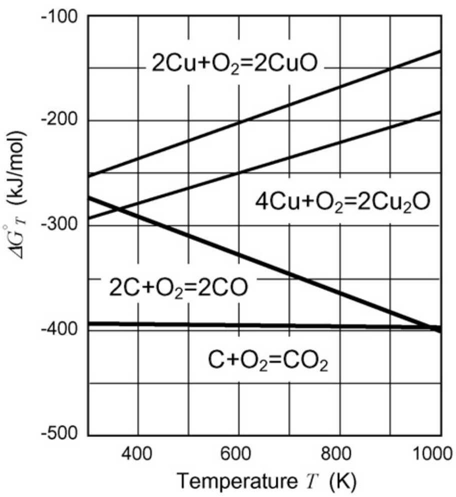

Fig. 1. Change in Gibbs free energy for oxide formation of copper and carbon for 1 mol oxygen.

occur because the change in Gibbs free energy, ΔG°_T, is negative; that is, ΔG°_T of the products is less than that of the reactants, as shown in Fig. 1. The value of ΔG°_T can be calculated from the following equation [7] and thermo-chemical data:

$$\Delta G^\circ_T = \Delta H^\circ_T - T\,\Delta S^\circ_T = \Delta H^\circ_{298\,\mathrm{K}} + \int_{298\,\mathrm{K}}^{T} \Delta C_P \mathrm{d}T - T\,\Delta S^\circ_{298\,\mathrm{K}} - T\int_{298\,\mathrm{K}}^{T} \frac{\Delta C_P}{T}\mathrm{d}T \quad (1)$$

where ΔH° is the standard enthalpy change, ΔS° is the standard entropy change, ΔC_P is the difference between the heat capacities of the reactants and products at constant pressure, and T is the temperature.

Fig. 1 also shows that ΔG°_T for the oxide formation of carbon is more negative than that of copper. ΔG°_T measures the chemical affinity of reactants to oxygen. Hence, the oxides CO_2 and CO are more stable than the oxides Cu_2O and CuO. This suggests that when carbon atoms are close to copper oxides, the carbon atoms deoxidize them and are themselves oxidized. Therefore, by bringing a diamond into contact with copper oxides in air at temperatures higher than room temperature, it is possible to remove carbon atoms from the surface of a diamond.

3. Properties of thermo-chemical polishing

3.1. Experimental procedures

Since the occurrence of chipping of cutting edge depends largely on surface microcracks induced by mechanical polishing, the diamond surface must be free of such cracks. Therefore, the depth of the layer of diamond removed by the oxidization–deoxidization reaction must be more than several nanometers to remove the microcracks. Furthermore, for longer tool life, the surface of the diamond must be as smooth as possible. In order to investigate whether the thermo-chemical polishing technique satisfactorily met these requirements, experiments on diamond polishing were carried out as follows.

The (1 0 0) plane of a diamond specimen was brought into contact with a stationary pure copper plate heated in air to temperatures from 323 to 523 K. The specimen was a natural monocrystalline diamond, which was mechanically polished as smooth as the rake faces of diamond tools. On the surface of the specimen, a tiny ring crack was produced to measure the depth of the diamond layer removed by the oxidization-deoxidization reaction. After each thermo-chemical polishing, the diamond surface was measured with a scanning probe microscope, and then its surface roughness and fractal dimension were evaluated.

In addition, Hertzian fracture tests [8] were carried out to indirectly investigate whether surface microcracks could be reduced by thermo-chemical polishing. The test involves pressing a spherical diamond indenter with a 50 μm tip radius on the flat specimen surface. If microcracks exist at the maximum tensile stress circle of the contact area, a ring crack fracture occurs. In this test, the crack initiation was detected by the acoustic emission (AE) signal, and the fracture strength of the specimen was calculated from the average contact pressure at the moment of fracture.

3.2. Results

Fig. 2 shows the depth of the diamond layer removed by contact with the copper plate heated to 523 K in air. The depth increases almost linearly with contact time and reaches approximately 7 nm after 6 h. If this removal is due to the oxidization–deoxidization reaction, the volume of the diamond layer removed in a unit time interval, which is known as the removal rate, would have an exponential temperature dependence, which would be given by the Arrhenius law, because the temperature dependence of chemical reaction rate V is generally described by the following Arrhenius equation:

$$V = A\,\exp\left(-\frac{E}{RT}\right) \quad (2)$$

where A is the pre-exponential factor, E is the activation energy, R is the gas constant, and T is the absolute temperature.

Fig. 3 shows an Arrhenius plot of the removal rate versus copper-plate temperature. As the copper-plate temperature becomes higher, the removal rate increases linearly. Thus, the temperature dependence of the removal rate obeys the Arrhenius law. The apparent activation energy for diamond removal, determined by the equation fitting the line shown in Fig. 3, is estimated to be 218 kJ/mol. This means that the diamond surface can be polished by bringing the diamond into contact with copper oxides.

Next, the surface characteristics of the thermo-chemically polished diamond are described. Fig. 4 shows profiles of the mechanically and thermo-chemically polished diamond surfaces. The profiles are visibly different. Compared with the mechanically polished surface, the thermo-chemically polished one appears smooth. To quantify the difference between these profiles, the surface roughness and fractal dimension were investigated.

As shown in Fig. 5, thermo-chemical polishing decreases the surface roughness, because peaks on the diamond surface in con-

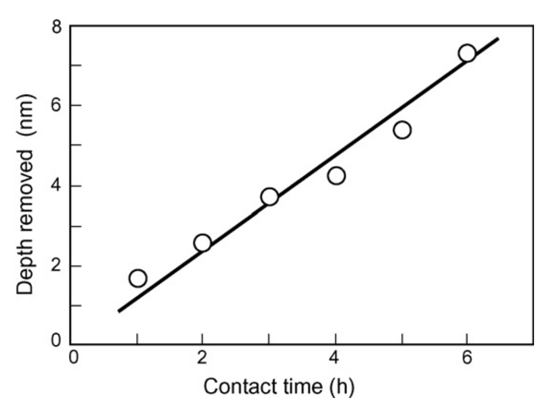

Fig. 2. Variation in depth of diamond layer removed with contact time.

Download English Version:

https://daneshyari.com/en/article/804706

Download Persian Version:

https://daneshyari.com/article/804706

Daneshyari.com