Mechanical Properties of Oxide Films on Electrolytic In-process Dressing (ELID) Copper-based Grinding Wheel

J C Kuai¹, J W Wang¹, C R Jiang¹, H L Zhang² and Z B Yang¹

¹School of Mechanical and Power Engineering, Henan Polytechnic University, Jiaozuo, Henan, 454003, PR China.
²School of Mechanical Engineering, Nantong University, Nantong, Jiangsu, 226019, PR China.
E-mail: hitgjc@163.com

Abstract. The mechanical properties of oxide films on copper based grinding wheel were studied by nanoindentation technique. The analysis of load displacement shows that the creep phenomenon occurs during the loading stage. Results show that the oxide film and the matrix have different characteristics, and the rigidity of the copper based grinding wheel is 0.6-1.3mN/nm, which is weaker than that of the matrix; the hardness of the oxide film is 2000-2300MPa, which is higher than the matrix; and the elastic modulus of the oxide film is 100-120GPa, also higher than the matrix.

1. Introduction

ELID grinding technology is widely used in the field of ultra-precision grinding of hard and brittle materials, because the grinding wheel surface coated with oxide film, which has auxiliary polishing effect, then can get a high grinding quality[1]. It can be seen that the performance of the oxide film produced by the electrolysis of the grinding wheel surface becomes a key factor affecting the grinding quality, and many researchers have conducted extensive and deep research on the performance of the oxide film[2-5]. Some researchers simplify the oxide film to "spring", one end was connected with the grinding wheel matrix, and the other end was loaded with abrasive grains. In the ultra-precision grinding, the "spring" instead of grinding wheel friction polishing, therefore, ELID grinding can get high precision grinding surface[6]. But researchers doesn't know much about the mechanical properties of the “spring”. Writer have been studied the mechanical properties of the oxide film on the iron based grinding wheel, and the effects of the grinding depth, feed rate and other process parameters on the hardness, elastic modulus and stiffness of the oxide film on the grinding wheel surface[7]. However, copper based grinding wheel is often used in high efficiency grinding in ELID grinding, and the mechanical properties of the oxide film on the grinding wheel surface are rarely reported.

In this study the mechanical properties of the oxide film on the copper matrix grinding wheel was measured by nanoindentation technique, and tested the hardness, elastic modulus and stiffness of the oxide film on the copper based grinding wheel.
2. Experimental Instruments and Methods

2.1 Experimental instruments. CSM instrument SA UNHT-type ultra nanoindentation instrument; Berkovich diamond indenter; the experiment was carried out in 10000 levels of ultra clean environment, the atmosphere of the environment medium was air, and the ambient temperature was 24±0.5°C; W40 copper based grinding wheel; ELID power supply; ELID electrolyte; MM7140 surface grinder.

2.2 Experimental methods. Put the W40 copper based grinding wheel in the MM7140 surface grinder which has the ELID electrolytic device, and start electrolytic polishing and grinding experiment, electrolytic and grinding parameters are shown in Table 1.

Table 1 ELID electrolytic and grinding parameters of copper based grinding wheel

| Electrolytic voltage U(V) | Electrolytic current I(A) | Electrolytic pulse width t(on)(µs) | Electrolytic pulse spacing t(off)(µs) | grinding speed Vs(m/s) | grinding depth AP(mm) | feed rate F(mm/min) |
|--------------------------|--------------------------|-----------------------------------|----------------------------------------|------------------------|-----------------------|---------------------|
| 60-120                   | 20-50                    | 0-99                              | 0-99                                   | 15.7                   | 0.001-0.01           | 20-50               |

After the end of the ELID electrolytic grinding, use wire cutting machine to cut the surface of the copper based grinding wheel with oxide film part, about 20mm*30mm*10mm, for nanoindentation test; a total of 4 test depth: 0.001mm, 0.002mm, 0.005mm, 0.01mm, each test depth was repeated 4 times and the average was taken as the test result.

3. Results and discussions

3.1 Variation of load and displacement with time. As shown in Figure 1a)-1d), it’s nanoindentation loading curve, load displacement are 0.001mm, 0.002mm, 0.005mm, 0.010mm. From Figure 1a), the maximum load is Fmax=59.74mN, the maximum displacement is hmax= 1039.93nm; Figure 1b), the maximum load is Fmax=217.78mN, the maximum displacement is hmax= 2010.02nm; Figure 1c), the maximum load is Fmax=874.23mN, the maximum displacement is hmax= 5024.99 nm; Figure 1d), the maximum load is Fmax=1637.60mN, the maximum displacement is hmax= 10078.94nm. When the load is 0.001 mm, it can be seen from the unloading curve Fn and displacement curve Pd, only a small amount of elastic recovery, large plastic deformation occurred, and elastic recovery is 50 nm; when the load is 0.002 mm, elastic recovery is 300 nm; When the load is 0.005 mm, elastic recovery is 700 nm; When the load is 0.01 mm, elastic recovery is 1700 nm. It is found that the elastic recovery increases with the increase of the load depth, which indicates that the influence of the grinding wheel matrix increases. In addition, from the elastic recovery of the oxide film and the change of the load in figure 1 we can see, the elastic coefficient of the oxide film of the grinding wheel is not constant, but varies. The elastic coefficient increases with the increase of the load depth.

![Figure 1a) load depth 0.001mm](image1)

![Figure 1b) load depth 0.002mm](image2)
3.2 Variation of load and displacement. As shown in Figure 2a)-2d), it’s nanoindentation load displacement curve, load displacement are 0.001mm, 0.002mm, 0.005mm, 0.010mm. Fig. 2a) shows that there is creep phenomenon at the displacement 0-100nm; Figure 2b) shows that there is creep phenomenon at the displacement 1250-1500nm; Figure 2c) shows that there is creep phenomenon at the displacement 3000-3500nm.

3.3 Variation of stiffness, hardness and modulus of elasticity. Figure 3 shows that the oxide film stiffness increases with the increase of indentation depth. At the initial stage, the slope of the
0.001-0.002 mm indentation depth is larger, and then tends to be gentle. This is due to the thin film formed on the copper based grinding wheel, only a few microns. Therefore, the measured indentation depth exceeds the binding site of the oxide film and the matrix, and presents different characteristics in the binding site.

Figure 3. Nanoindentation test of the stiffness of the oxide film

Figure 4 is the change curve of the hardness of the oxide film and the indentation depth. It can be seen from Fig. 4 that with the increase of the indentation depth, the hardness of the oxide film increases first and then decreases, which shows the two different variation characteristics of the former and the latter. When the indentation depth is 0.001-0.002 mm, the hardness of the oxide film is measured at this time, about 2000-2300 MPa; as the indentation depth increases to 0.005 mm, the indenter is at the binding site of the oxide film and the copper based grinding wheel, and the curve shows that the hardness drops to about 1000 MPa; when the indentation depth is increased to 0.01 mm, the indenter has clearly crossed the binding site of oxide film and copper based grinding wheel matrix, and test the composite hardness of the grinding wheel matrix and oxide film, the hardness decreased to 700 MPa, shows the different characteristics of oxide film formed after electrolytic and the matrix. The hardness of the oxide film is much higher than that of the copper based grinding wheel matrix. This seems to indicate that the polishing performance of copper based grinding wheel oxide film is poor, and the superhard oxide film seems to be easier to scratch the finished surface.

Figure 4. Nanoindentation test of hardness of the oxide film.

Figure 5 is the change curve of the elastic modulus of the oxide film and the indentation depth. It can be seen from figure 5 that the elastic modulus decreases from 120 GPa to 60 GPa with the increase of
indentation depth. When the indentation depth is 0.001-0.002mm, the elastic modulus of oxide film is measured, about 100-120GPa; when the indentation depth is 0.005-0.010mm, the indenter has been crossed the oxide film, and entered into the copper based grinding wheel matrix at this time. Therefore, the elastic modulus is the composite elastic modulus of oxide film and the matrix, about 60-80GPa. It follows that the elastic modulus of the oxide film is different from that of the matrix, the elastic modulus of the oxide film is higher than that of the matrix.

Figure 5. Nanoindentation test of elastic modulus of the oxide film

4. Summary
This paper studied the mechanical properties of the oxide film on the copper based grinding wheel, and obtained some useful results:
1. The elasticity of the oxide film on the copper based grinding wheel is weak, and its elastic coefficient is not constant, should be regarded as a spring damping system with variable elastic coefficient;
2. The hardness of the oxide film on the copper based grinding wheel is as high as 2000-2300MPa, which is much higher than that of the matrix, and that's mean the oxide film seem not to be suitable for the auxiliary polishing in ELID grinding;
3. The oxide film of the copper based grinding wheel has high elastic modulus, as high as 100-120GPa, which is higher than the elastic modulus of the matrix.

5. Acknowledgments
This work was supported by the National Natural Science Foundation, China (Grant No. 51475147), and by the key project of Henan Province Science and Technology Research (Grant No. 13A460341). Also funded by the Natural Science Foundation of the Jiangsu Province, China (Grant No. BK20150406) and the technical project of Nantong, China (Grant No. MS12016015).

References
[1] Gao D X, Liu Q, Zhang B, Xiao C X, Ren C Z. 2016 Research on formation mechanism of grinding wheel oxide film in ELID ultra precision mirror grinding Materials Science Forum 861 90-96.
[2] Tang H, Deng Z H, Guo Y S, Qian J, Reynaerts D. 2015 Depth-of-cut errors in ELID surface grinding of zirconia-based ceramics International Journal of Machine Tools & Manufacture 88 34-41.
[3] Wu M L, Zhang K F, Ren C Z. 2015 Study on the non-uniform contact during ELID groove grinding Precision Engineering 39 116-124.
[4] Zhang H L, Kuai J C. 2017 Forming mechanism of -Fe2O3in the oxide films on iron-bonded diamond wheel surface by ELID grinding Key Engineering Materials. 723 434-438.

[5] Kuai J C. 2013 Friction coefficient of nano-ceramic polished by oxide film on elid grinding wheel Advanced Materials Research. 669 91-94.

[6] Kuai J C, Zhang H L, Zhang F H, Zhang Y. 2010 Research on minimum mechanism of roughness of ELID grinding Advanced Materials Research 135 441-446.

[7] Kuai J C, Zhang F H, Zhang Y. 2010 Mechanical Properties of Oxide Film on ELID Grinding Wheel Surface Nanotechnology & Precision Engineering. 8 447-451.