Mechanical Behavior of Iron-bonded Grinding Wheel after ELID (Electrolytic In-process Dressing) Electrolysis Procedure by Nanoindentation

To cite this article: Jicai Kuai and Huali Zhang 2017 IOP Conf. Ser.: Mater. Sci. Eng. 250 012047

View the article online for updates and enhancements.

You may also like
- Multi-modal sensing using photoactive thin films
  Donghyeon Ryu and Kenneth J Loh
- Formation of ultrathin Ni germanides: solid-phase reaction, morphology and texture
  K van Stiphout, F A Geenen, B De Schutter et al.
- Numerical Simulation Study on Characteristics of Airtight Water Film with Flow Deflectors
  Zhang Weikang and Gong Hongwei
Mechanical Behavior of Iron-bonded Grinding Wheel after ELID (Electrolytic In-process Dressing) Electrolysis Procedure by Nanoindentation

Jicai Kuai a and Huali Zhangb*

aSchool of Mechanical and Power Engineering, Henan Polytechnic University, Jiao Zuo, China 454003
bSchool of Mechanical Engineering, Nantong University, Nantong, China 226019
*Corresponding author: hualiz@ntu.edu.cn

Abstract. We have evaluated the effect of oxide films on polishing behavior during ELID grinding process. The evaluation procedure used nano-indenter to analyze quantitatively the oxide film’s mechanical properties on iron-bonded grinding wheel after ELID electrolysis. As a result, the oxide film’s mechanical properties increased with the indent depth increasing. The plots of indent load and displacement for oxide films showed slight variations with time. The content of iron group elements in grinding wheel also has higher impact on oxide film’s properties.

1. Introduction
The friction and wear performance of oxide film on grinding wheels after ELID grinding has been gaining interest in the early 2000s, which was originated by T Kato [1]. Our early reports and results show that the friction and mechanical behaviors of oxide films by ELID grinding have profound effects on its polishing ability [2-3]. Furthermore we have explored the chemical composition and transformation procedure of oxide films and their influences on polishing ability [4]. And much is known about oxide film’s temperature reduction performance [5]. Moreover, the microstructure of oxide film has shown to be core of diamond abrasive grits, surrounding with a thin film of iron oxides, and the outermost layer of α-Fe2O3 composite grits [6]. The polishing ability of oxide films is confined to the existence of α-Fe2O3 [7].

These reports were based on static state of oxide films. However, grinding with oxide film is not a static condition as expected. Oxide films are wore out and then electrolyzed to form new films under a dynamic change process by ELID grinding. These early studies have described a certain state during oxide films’ dynamic change and couldn’t represent actual performances of oxide films. And here we will focus on the dynamic variation rule of oxide film to obtain better understandings of its properties and effect on polishing procedure. The motivation of the present study is to evaluate the mechanical properties of oxide films on iron-bonded grinding wheels under dynamic conditions. Nano indentation tests are conducted to experiment the main features of oxide film’s microstructure and its effect on hardness, stiffness and elasticity modulus of oxide films.

2. Method and Experimental Setup
Olive WC&Pharr GM developed a improved method using nano indentation experiments for determining mechanical properties of materials, especially for thin film materials. We believe it quite feasible using nanoindentation experiment for oxide film on the surface of grinding wheels. However,
what needs to be clarified is that the indenting tip should keep away from abrasive grits as to obtain correct results. The indentation depth value obtained from this measurement was about 1-10µm, 1/10 of oxide film’s thickness. Each indentation depth was repeated testing for 5 times. Average value was taken after indenting and represented the mechanical properties of oxide film.

In order to measure online properties of oxide films, electrolyzed abrasive wheel is necessary. In this study the grinding wheel used was W 40 iron-bonded wheel. Grinding process was followed after electrolysis using MM7120 surface grinder with ELID-5 electrolyte. Values of grinding parameters are shown in Table 1.

Table 1. Electrolysis and grinding parameters.

| Supply voltage(V) | Current (A) | Pulse width (µs) | Pulse interval (µs) | Grinding speed (m/s) | Grinding depth (mm) | Feed speed (mm/min) | Content of iron group bond |
|------------------|-------------|------------------|--------------------|----------------------|---------------------|---------------------|--------------------------|
| 60-120           | 10-50       | 1-99             | 1-99               | 15.7                 | 0.001-0.01          | 150-300             | 30%-90%                  |

3. Results and Discussion

3.1. Indentation Response of Oxide Films

The fact that oxide films on the wheel surface are compressible due to their porous microstructure, should help understand the indentation response of iron-bonded grinding wheels. Mechanical properties of grinding wheels were tested with a displacement of 0.001mm, 0.002mm, 0.005mm and 0.01mm by nano indenter, as shown in Figure 1. Moistened porous inside the oxide films reserved considerable number of electrolyte, while dry porous appeared hollow structure. With the indent load increasing, amounts of mirco porous were collapsed. And the resulting loading curves appear slight fluctuations during loading process (see Figure 1 a), and b) with indent displacements of 0.001mm and 0.002mm, respectively). Figure 1 c) and d) show constantly changing in loading curves with indent displacement of 0.005mm and 0.001mm. In this case, the indent tip was pierced through the oxide films and reached to the grinding wheels. The wheels were made of rather dense composite metal structure before electrolysis, with 70% iron group metal and 20% bronze, nickel, cobalt, carbon and etc. And hence no obvious fluctuations in the loading curves were shown.
Similar to applied load as a function of loading time, curves of load force versus indentation depth show same change trend as shown in Figure 2. With low indent displacement of 0.001mm and 0.002mm, the loading process was conducted inside the oxide films and the resulting loading curves presented slight fluctuations due to oxide films’ microstructure (as shown in Figure 2 a) and b)), because the applied load could actually cause the micro porous in the oxide film to collapse. While with larger indent displacement of 0.005mm and 0.01mm, the oxide film’s microstructure does not affect the loading curves much, and this suggests the load force was applied directly onto the wheels. In contrast to low displacements, larger displacements follow a relatively smooth curve of load force as a function of indentation depth as shown in Figure 2 c) and d).

**Figure 1.** Indentation depth as a function of load time with different displacements
3.2. Observation of Oxide Film Microstructure

In order to investigate the presence of porous structure, oxide film of grinding wheels was observed using SEM and the images obtained are shown in Fig. 3 a) and b). From these figures it can be seen that bump ups and downs of loose structure with a great amount of porous. Large crack can be observed in dry oxide film and easy to break off. Multi sizes of holes were found all over the oxide film, which can explain the reason for slight fluctuations in nano indent loading curves.
3.3. Mechanical Measurements of Grinding Wheels

Experiments were carried out with indent displacement from 0.001mm to 0.01mm. Figure 4 shows the variations of stiffness, hardness and elasticity modulus of W10 grinding wheel (grain size W10, 100% concentration of iron-bond, and 90% content of iron group elements) recorded during nano indentation tests. The results obtained from the early stage (with indentation depth from 0.001mm to 0.01mm) were found to be actual oxide films’ mechanical properties. The stiffness of oxide films on the grinding wheel was from 0.1117mN/nm to 11.6030mN/nm. The hardness was from 357.87 to 4833.8MPa. And the elasticity modulus of oxide films ranged from 17.92GPa to 237.1GPa. Then mechanical behavior along indentation depth down above 0.005mm, were measured for both the oxide film and the grinding wheel, in which the corresponding mechanical data are combined with the oxide film and the grinding wheel.

The mechanical properties of the grinding wheel increased with indentation depth, indicating that the oxide film on the wheel was elastic and of variable stiffness. Stiffness and elasticity modulus of oxide film increased with indentation depth. However, the hardness value clearly shows a decreasing trend with indentation depth (lower than 0.002mm) at the early stage of indenting. It is likely that some diamond grits beneath the oxide film caused local changes in hardness curve.

Figure 4. Variations of mechanical properties of W10 grinding wheel
3.4. Effect of Grinding Wheel Components

Nano-indentation test was repeated on iron-bonded diamond grinding wheel, which was of W40 grain size, 100% iron-bond, and 90% iron group elements. Results were displayed in Fig. 5. Stiffness value of W 40 wheel was 4-14μN/nm, hardness 210MPa, and elasticity modulus was between 30 to 80 GPa. Comparing W40 with W10 grinding wheel, interesting results were obtained that stiffness of 70% iron group elements wheel was 10 times larger than 90% iron group elements, hardness 3-5 times larger and elasticity modulus increased 3-5 times.

In addition to consisting less iron group elements, W10 grinding wheel contains almost 30% bronze bond and a small amount of nickel, cobalt and carbon. And their oxides formed thin composite film and thus changed the mechanical properties of oxide film in grinding wheel. For this thin composite film, hardness of copper oxides is higher than iron oxide. Therefore, W10 grinding wheel presents higher mechanical properties than W40 grinding wheel due to its chemical composition. However, the forming ratio of Fe2O3 reduced as a result of less iron group elements by grinding heat, and weakened the polishing ability of grinding wheels. Thus, bonding formula of grinding wheels should be given consideration to take account of oxide film’s mechanical properties and its polishing ability.

4. Conclusion

From our studies conducted with nano-indenter on mechanical properties of iron-bonded diamond grinding wheel, the following conclusions may be drawn:

1) The response of the indentation process onto the oxide films, which was described in indent-loading curves, is found to be of slightly variation with loading. The porous microstructure of the oxide films was predicted to collapse during indenting and hence this could interpret the slight variation in loading curve.

2) We have used nano-indenter to study the mechanical behavior of diamond grinding wheel with 70% iron content, focusing on the effect of iron level. Level of iron group elements in iron bond grinding wheel ultimately affects the mechanical properties of the oxide films after electrolysis.

3) Mechanical measurements on the oxide films of grinding wheels show that mechanical properties of 70% content in iron group elements is higher than those of 90% content. This feature is likely related to more copper family elements in 70% iron-bonded grinding wheels, which in return reacts to form high hardness copper oxide during electrolysis process.

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).

6. References

[1] Kato T, Itoh N, Ohmori H, Katahira K, Lin W, Hokkirigawa K 2004 Key Engineering Materials 257 257
[2] Kuai J C 2013 Advanced Materials Research 669 91
[3] Kuai J C, Zhang F H, Zhang Y 2010 Nanotechnology and precision engineering 8 447
[4] Kuai J C, Wang J W, Jiang C R 2016 MATEC Web Conf. 67 1
[5] Kuai J C 2017 Nanomaterials and Energy 6 1
[6] Kuai J C, Jiang C R, Wang J W 2016 Key Engineering Materials 709 77
[7] Kuai J C, Ardashev D V, Zhang H L 2017 Modern Physics Letters B 31 1