Investigation of α-Fe$_2$O$_3$ in Oxide Film of Electrolytic In-process Dressing Wheel and Its Effect on Polishing

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Abstract. This study aims to experiment and to analyze the generation and transformation mechanism of α-Fe$_2$O$_3$ in oxide film on Electrolytic In-process Dressing wheels. The main objective is to study α-Fe$_2$O$_3$’s effect on polishing performance. The electrochemical process of generation and transformation of α-Fe$_2$O$_3$ in the oxide film was analyzed. The content of α-Fe$_2$O$_3$ in the oxide film was measured using X-ray diffractometer. Furthermore non-abrasive iron bonded wheel was proposed and its application was then discussed.

1. Introduction
ELID (Electrolytic In-process Dressing) grinding technique holds tremendous promise for ultra-precision grinding processes. Among other advantages, the oxide film, which formed on the surface of wheels after electrolysis dressing, has effectively functions, such as absorbing vibration, moderating impact, separating the abrasive grains and polishing the workpiece. In the area of ELID grinding there has significant interest in better understanding the property and function of the oxide film for surface finish accuracy and quality.

The oxide film on ELID grinding wheel surface has been gaining popularity in the late 90s. Shaving experiments have been conducted for studying the content, cross section structure and forming procedure of the oxide film by ELID grinding [1]. Early reports and results show that the majority content of oxide film is all kinds of iron oxides. The hardness and adhesiveness of fresh oxide film after electrolysis was proved to be minimal [2]. Conventional mechanical tests on oxide films including rigidity, elastic modulus and contact stiffness are valuable [3-5]. ELID grinding has been considered as a compounding process of grinding, grounding and polishing by oxide films [6]. We have reported a test on ELID grinded nano-ceramic material by oxide film polishing process, and proved the friction coefficient of nano ceramic decreased with grinding depth and feeding speed increased [7]. And we have focused on process parameters of ELID grinding that recognize the grinding depth factor on the adhesiveness of the oxide films [8]. In addition, B Kersschot has studied other process parameters’ effect on electric double layer, electric resistance, growth speed of oxide films, including provided power, electrolyte, speed of wheel and abrasive grain [9-10]. The author researched the mechanical property of the oxide film on ELID wheel and the forming mechanism of α-Fe$_2$O$_3$ in the oxide film on the ELID wheel [11-12].
This paper presents the findings on the oxide film components and its effect on polishing performance on basis of previous studies by others. The electrochemical formation and transformation process of $\alpha$-Fe$_2$O$_3$ in the oxide film is discussed in this study. The possibility of existence of $\alpha$-Fe$_2$O$_3$ in the oxide film was successfully proved by theoretical analysis. The content of $\alpha$-Fe$_2$O$_3$ in the oxide film was then measured using X-ray diffractometer (XRD). The influence factors of $\alpha$-Fe$_2$O$_3$ and its polishing properties were examined. Non-abrasive-grain iron bonded grinding wheel and its potential application were proposed.

2. Experimental setup
Powder X-ray diffraction (XRD) measurements were performed on a Max-RC typed diffractometer (Rigaku, Tokyo, Japan) with Cu-Ka radiation from 20°~ 80°at a scanning speed of 6 (°)/min. ELID grinding was carried out using iron-based diamond abrasive wheels on a MM7120A surface grinder. The grinding wheel speed was maintained 1500r/min and the feed rate was fixed to 10m/min. Grinding depth was set to be 0.001mm, 0.003 mm, 0.005 mm and 0.01 mm. And the spindle static stiffness was 100N/µm. Diamond grinding wheels were of grain sizes 40µm, 10µm and 1.5µm (grit size: W40, W10 and W1.5), and the mass concentrations were 100%, 50% and 25%, respectively. A high-frequency pulse was supplied from the ELID mirror surface grinding power supply (HDMD-V). The amplitude of the applied voltage was 60~120 V and the current was set from 0~50A. The pulse width was supplied to 1-99µs and the inter-pulse was 1-99µs. ELID grinding liquid HDMY-V model was supplied at a dilution of 1:50. ZrO$_2$ ceramic workpiece of 200nm grain size (hardness of HRA87 and toughness of 12.2 MPa·m$^{1/2}$) was used for experiments.

3. Experimental procedure and results for $\alpha$-Fe$_2$O$_3$ in the oxide films
First of all the iron-based wheels W1.5, W10 and W40 were used to conduct ELID grinding experiments after 30 minutes pre-electrolysis treatment by MM7120 surface grinding machine, which coincides with electrolysis dressing unit. All values of the parameters are mention in Section 2. Grinding was stopped when reddish-brown oxide films were observed evenly adhering onto the surface of the wheels. And the oxide films were scraped away from the wheels and collected up, as Figure 1 shown.

![Figure 1](image_url)

Figure 1. Oxide film powder scraped away from the grinding wheels

XRD diffraction pattern of the oxide film from W40 wheel is shown in Figure 2. The patterns show that there are several types of iron oxides and hydroxides, including 2 and 3 valent iron. It could be remarked that there are also $\alpha$-Fe$_2$O$_3$, $\beta$-Fe$_2$O$_3$, $\gamma$-Fe$_2$O$_3$, FeO, Fe(OH)$_2$ and Fe+3O(OH) in the oxide film. The evolutionary process of iron oxides was also checked from value obtained from this pattern. As grinding processes, the surface layer of the oxide film transformed to $\gamma$-Fe$_2$O$_3$, $\beta$-Fe$_2$O$_3$, and $\alpha$-Fe$_2$O$_3$·H$_2$O, eventually. Under the continuous action of grinding heat in the grinding zone, iron oxides then lost crystalliferous water and transformed into $\alpha$-Fe$_2$O$_3$. And there are still other intermediate valence states underneath the wheel surface. The surface layer of oxide film scraped might confound with the base layer. Hence all types of valence state iron oxides can be found in XRD results. The XRD pattern showed some heterogeneous components except the above-mentioned iron oxides and hydroxides, because the components of the wheels consist of iron, copper, tin, nickel and graphite. It
may result confused data in this case. So Figure 2. Simple marked three evident pairs of diffraction peaks of \( \alpha\)-Fe\(_2\)O\(_3\).

![XRD pattern of oxide film in W40 grinding wheel](image)

**Figure 2.** XRD pattern of oxide film in W40 grinding wheel

4. Discussions

4.1. Effect of the particle sizes on transformation of \( \alpha\)-Fe\(_2\)O\(_3\)

XRD diffraction patterns of three different particle sizes (W40, W10 and W1.5) were also checked which is shown in Figure 3. And three pairs of \( \alpha\)-Fe\(_2\)O\(_3\) main peaks obtained from this measurement were distributed at 33.16°, 35.61°, 49.93°, 54.04°, 62.40° and 65.45°. The diffracted intensity increased gradually whereas the particle size of the wheels decreased. This variation of particle size causes added oxide films involved in grinding process and therefore transform more \( \alpha\)-Fe\(_2\)O\(_3\) in the oxide films.

![XRD measurement of W40, W10 and W1.5 particle sizes](image)

**Figure 3.** XRD measurement of W40, W10 and W1.5 particle sizes
4.2. Mass concentration of the wheels
Variations in diffracted intensity of α-Fe₂O₃ within the oxide films were measured under different mass concentration of the wheels (100%, 50%, and 25%) plotted in Figure 3. The diffracted intensity value obtained from this measurement increased with decreasing mass concentration. From this figure it can state that volume fraction of the abrasive particles decreased with decreasing mass concentration. The more volume fraction of the binder, the more iron based binder involved in electrochemical reaction during ELID grinding processes. The formation and subsequent transformation of α-Fe₂O₃ in the oxide films gradually matured. The wheels exhibited increasing amount of α-Fe₂O₃ with less mass concentration, consequently.

In common, the ultra-precision grinding processes with finer particle size showed better grinding performance. The less mass concentration of the wheels resulted in smaller particle size to avoid the wheel blocked up. Thus, compared to other conditions, only less mass concentration (25% in this case) of the wheel exhibited its suitability to ultra-precision grinding, which is identical to the general knowledge in ultra-precision machining.

4.3. Correlation of α-Fe₂O₃'s content with polishing effect
As an abrasive α-Fe₂O₃ is second in grinding effect only to cerium based polishing powder. The formation and transformation of α-Fe₂O₃ in the oxide film is the fundamental cause how the oxide films work on grinding and polishing procedures. The transformation of α-Fe₂O₃ tends to complete while the oxide films operating the electrochemical reaction due to the grinding heat per grinding pass. It could be observed that the content of α-Fe₂O₃ in the oxide films gradually increased and eventually formed an abrasive film with finer grain size onto the surface of the grinding wheel, as shown in Figure 4 and Figure 5. The grain size of α-Fe₂O₃ obtained from our measurement was only 5-10nm. Nano-scaled α-Fe₂O₃ has a minor effect on polishing process and lower removal ability. Some α-Fe₂O₃ abrasive grains tended to gather via cluster state due to ease of reactivity, and formed membrane structure adhered to the grinding wheel surface. Therefore, it can be concluded that polishing ability of the oxide films on the abrasive wheel surface is a cooperative phenomenon with many α-Fe₂O₃ grains in membrane structure.

The grinding and polishing effect of the oxide films is estimated to be valid only in ultra precision grinding. The reason is that the oxide film is far thicker than the grinding depth in ultra precision grinding, and there is no direct contact between the workpiece and the abrasive grains with the oxide films separated in between.
5. Non-abrasive iron bonded grinding wheel

The traditional iron bonded grinding wheel has lowered α-Fe₂O₃ content after electrolysis during ELID grinding. It is confirmed to have limited effect on polishing procedure. In order to study the polishing mechanism of α-Fe₂O₃, non-abrasive-grain grinding wheel was fabricated with no diamond abrasive grains. We would like to investigate the fundamental principle in ELID ultra precision grinding only on the effort of α-Fe₂O₃ in the oxide films. We are planning to increase the formation ratio from γ-Fe₂O₃ to α-Fe₂O₃ to achieve it in future work.

6. Conclusions

Experimental studies of the oxide film’s components for the grinding wheels during ELID have been conducted. The formation and transformation mechanisms of α-Fe₂O₃ were presented and discussed by XRD and TEM results. These results were in agreement with the transformation mechanism of α-Fe₂O₃ that we have predicted.

The following conclusions are from our analyses:

1. The components of the oxide film on grinding wheels during ELID process have been investigated and hence the formation and transformation of α-Fe₂O₃ is found.
2. It could be observed that the grain size had certain influence on the content of α-Fe₂O₃ on the grinding wheel surface. The content of α-Fe₂O₃ increased with the grain size decreasing. The mass concentration also had certain influence on it and the content of α-Fe₂O₃ increased with the mass concentration lower.
3. The mechanism of the oxide film working on polishing effect during ELID grinding is of the coordination behaviour of numerous α-Fe₂O₃ particles which have formed membrane structure.
4. The concept of non-abrasive iron-bonded grinding wheels has been proposed in this study.

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