Analysis of passivation phenomena during ELID-grinding

B. Kersschot, J. Qian, D. Reynaerts

K.U.Leuven, Department of Mechanical Engineering, Belgium

Bruno.Kersschot@mech.kuleuven.be

Abstract

Metal-bonded wheels have a few advantages over normal grinding wheels, including higher stiffness, better thermal conductivity for removing process heat and high tool durability. This means grinding of hard materials like ceramics can be done more accurately; the tool life is longer; reshaping of the tool is delayed; and higher G-ratios can be achieved. To keep the super-abrasive metal-bonded grinding wheels sharp and to ground mirror-like surfaces, in ELID-grinding the wheels are dressed continuously and in-process through electrolytic passivation. An electric current between the anodic wheel and an external electrode can lead to the formation of an insulating layer covering the wheel. The goal of this study is to investigate the fundamentals in the growth of the layer in order to have a better understanding in the process. By analyzing the evolution of the voltage and current pulses generated by the power supply (Fuji ELIDER ED921) the layer growth can be monitored. At the start of pre-dressing, the cast iron bond (CIB) is purely metallic. The impedance of the electrolytic cell has a high capacitance and a small resistance. The current dissolves the iron which is then recombined with oxidizers of the electrolyte to form dense and insulating hydroxides. Measurements of the passivation layer resistance for different parameter settings show a steady rise until the insulation is completed. The results for different parameter settings are consistent with Faraday’s law which states that the accumulated charge governs the layer growth. From these experiments an equivalent electrical model is derived.

1 Evolution of voltage and current pulses during dressing

An experimental setup has been built up as shown in Figure 1 [1]. The upper brass part is the cathode, which is connected to the negative end of the ELID power supply. At the bottom a piece of cast iron as in a grinding wheel is fixed and it is connected to the positive end. The holder is mounted on a stage so that the CIB part can move left
and right to resemble the rotation of a grinding wheel. In between the two electrodes the electrolyte is supplied and the oxide starts to grow after applying a voltage.

**Figure 1: Dressing setup (left: the actual setup, right: schematic representation)**

An example of measured current and voltage during pre-dressing is illustrated in *Figure 2*, with power supply settings of 20A (peak current), 50% pulse duty ratio and 60V (output voltage). It can be seen that after 6 seconds (0.1 minutes) the voltage of the pulses changes from 5V to about 45V and the current from 0 to about 4A. At this time the loop resistance is 10Ω and this is entirely due to the resistivity of the electrolyte in the gap. With this resistance $R_0$ value, the resistivity of the fluid $\rho$ and the electrode area $A$, the gap width $l_g$ can be easily calculated with following formula:

$$l_g = \frac{R_0 \cdot A}{\rho}$$

In this case the gap is 0.5mm. While dressing the average voltage starts to rise and the pulses float upwards. This continues until the upper voltage reaches about 65V.

**Figure 2: Voltage and current pulses during pre-dressing**

Looking at the curves of the voltage downfall, it can be seen that the pulses are not straight, i.e. the voltage decays exponentially. This effect is more pronounced as the dressing advances in time. This figure explains, in line with the reports in literature on
ELID-grinding, why the mean voltage rises during dressing, while the current drops in the same time. The ELID power supply cannot generate negative current.

2 Electric equivalent of dressing process

An electrochemical reaction cell contains two double layers, at anode and cathode. Using the Helmholtz approximation of a double layer, the electrolysis process can be modelled as shown in Figure 3(a). $C_1$ is the capacitance of the anode, $R_{p1}$ its parallel resistance and $R_{s1}$ the series resistor. $R_{el}$ is the resistance of the electrolyte in the gap. The parallel resistance $R_{p2}$ is existent, but negligible, and therefore cancels the effect of $C_2$. This electric scheme can further be simplified to Figure 3(b), where $C_1$ is equal to $C$, $R_{p1}$ equal to $R_p$, and $R_s$ equal to the sum of $R_{s1}$, $R_{el}$ and $R_{s2}$.

![Figure 3: Electrical equivalent schemes of dressing process](image)

The voltage drop as depicted by the curves in Figure 2 contains two parts. First a steep voltage drop is noticeable, equal to $R_s\Delta I$, with $\Delta I$ the current drop. The second part is characterized by an exponential decay, i.e. the voltage stored over the capacitor causes a small current to flow through $R_p$ slowly dissipating a part of the voltage. This current only flows inside the loop consisting of $C$ and $R_p$.

3 Resistance evolution of the passivation layer

Based on the experiment data, the transient ‘total resistance’ of the oxide layer has been calculated (Figure 4). This resistance is a sum of resistors $R_s$ and $R_p$. A rise in value is clearly evident for different parameter settings and for a period of 20 minutes. Every curve starts with a 0Ω resistance, but after a short time, this increases. The oxide layer is thus not present immediately and it takes some time to form. At first the resistance growth is bigger than after a few minutes, when the resistance is still gaining but at slower pace. This is caused by secondary reactions. With the setting of 60V40A50%, the resistance is at (or at least close to) its maximum value (~180Ω) in the end. At this level the current mostly results in undesired reactions and byproducts. For other parameter settings, the high resistance (~180Ω) has not been reached after
20min. The resistance starts to rise earlier in the case of higher duty ratios (see curve 60V20A70%). This is according to Faraday’s law which states that a bigger amount of charge leads to more dissolution of the iron. However, after 12 min the 60V40A50% curve catches up with it. Remarkably, changing the peak current from 20A to 40A has little effect on the initial resistance growth (compare 60V20A50% to 60V40A50%). A reasonable explanation for this is that the initial current is too high for the piece causing excessive dissolution. This means there is a maximum current above which corrosion occurs. A voltage of 90V leads to 1.5 times the current flowing in the case of 60V. By using a higher voltage, more ions will dissolve and in addition there will be a bigger urge for them to precipitate. Not much difference is observed between measurements 60V20A50% and 60V20A30%. Finally, the presence of diamonds seems to have little influence, i.e. the curves of ‘CIB60V20A50%’ (without diamonds), and ‘CIBD60V20A50% (with #SD2000 diamonds) are very similar.

Figure 4: Evolution of the resistance of the oxide layer

Acknowledgement: This work was supported by Fonds Wetenschappelijk Onderzoek (FWO) – Vlaanderen grant G.A076.11 “Gecontroleerd ELID proces voor efficiënt en schadevrij slijpen.”

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