On the dressing behavior in ELID-grinding

B. Kersschot*, J. Qian, D. Reynaerts

KULeuven, Dept. Mechanical Engineering, Celestijnenlaan 300B, 3001 Leuven, Belgium

* Corresponding author. Tel.: +32-16322522; fax: +32-16322838. E-mail address: Bruno.Kersschot@mech.kuleuven.be.

Abstract

In Electrolytic In-Process Dressing (ELID) grinding the metallic wheels are kept sharp through an electrolytic passivation process. The outer part of the iron bonding is dissolved to form a passivating layer of oxides and hydroxides. This lowers the holding force of abrasives which are dulled during grinding and fresh abrasives are constantly protruding from the wheel.

This paper presents an electrical equivalent model of the electrolytic dressing process and explains how the total resistance of a grinding wheel changes during electrolytic dressing. At the beginning of the electrolytic dressing process, the interfaces between the fresh metallic wheel, the electrolyte and the external electrode are characterized by a high capacitance due to the presence of a double layer. Once the wheel is covered with a small passivating layer the capacitance is much lower because the charge cannot move freely in the oxides and hydroxides. Subsequently, as dressing continues, the growth of the layer leads to an increase in electrical resistance of the system. The total resistance is the key parameter to monitor the layer growth. Experimental results show the influence of power supply settings on the passivation speed of the grinding wheel. During the initial dressing minutes the resistances are increasing in a random way, independently of the electric power. The growth of the initial oxide layer depends on several random factors, such as the local amount of diamonds in the metal bonding and the actual gap width. Only after several minutes of dressing it becomes clear that the most powerful settings lead to the fastest growth in resistance, according to Faraday's law of electrolysis. The effects of the grinding speed and the abrasive grit size of the wheel are also shown in this paper. In general, lower wheel speeds lead to faster passivation and are therefore preferable during pre-dressing. Furthermore, the layer grows more rapidly in the case of big abrasives. Final experiments indicate that a commercially available electrolyte is not passivating the wheel at all. The substances of the used electrolyte are crucial to obtain a proper passivation.

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1. Introduction

“Electrolytic In-Process Dressing” (ELID)-grinding is an upcoming technique for processing very hard materials including ceramics and cermets. ELID-grinding enables the use of very durable metallic wheels which are normally experienced to have poor dressing properties. The process offers various benefits compared to the conventional grinding which is done with resin-bonded or vitrified grinding wheels.

1.1. Benefits of ELID-grinding

Especially for very small average grit sizes, in the order of 1µm, metallic wheels are known to lose their cutting ability very rapidly due to wheel loading. With the use of the electrolytic dressing principle in ELID-grinding it is possible to grind the hardest materials with relatively low wheel wear volumes (i.e. with high G-ratios). Because of the low wear the metal-bonded wheels benefit from a better shape retention. Also metallic wheels are much stiffer than the conventional resin-
bonded or vitrified ones, which is favorable for accurate machining. Furthermore it is possible for the wheels to hold very small grits, down to the magnitude of a few microns and smaller. Using these wheels of very fine mesh sizes it is possible to obtain a very good surface quality by ELID-grinding, with surface roughness Ra down to the nanometre level [1][2]. ELID-grinding with very fine abrasive wheels can bridge the gap between grinding and polishing. In principle, grinding leads to an accurate workpiece shape but leaves behind a poor surface finish with Ra values higher than 0.1 µm in common practice. Polishing, on the contrary, usually ameliorates the surface roughness but often deteriorates the figure accuracy of the part. This means that with ELID-grinding the obtained accuracy of the ground workpiece is better than after conventional polishing and, depending on the application, less polishing time is required or the polishing step even becomes obsolete. Finally, it is not required to re-clamp the workpiece on a polishing machine because the finishing step can be completed on the same machine. Figure 1 shows an example of an ELID-ground workpiece of an alloy of zirconia and titanium oxide. This workpiece has a length of 50 mm and a width of 20 mm.

1.2. ELID-grinding principle

In ELID-grinding a metallic grinding wheel maintains its sharpness through an electrolytic passivation process. The outer part of the iron bonding is dissolved to form a passivating layer of oxides and hydroxides. The oxides have an insulating effect and lower the current which flows through the wheel towards an external electrode. Due to this decrease in current less iron molecules will dissolve, which makes this a self-regulating process. Once the wheel is pre-dressed and thus covered with a sufficiently insulating layer of oxides, the actual grinding can begin. During grinding parts of the oxide layer wear off due to mechanical contact and the resistance in the electric current loop drops. More current will flow, again more ions will dissolve and finally recombine to restore the passivation layer. This layer essentially lowers the holding force of abrasives which are dulled during grinding, making fresh abrasives protrude constantly from the wheel.

In order to find favorable grinding conditions and to achieve good surface qualities and high shape accuracies, it is important to have a comprehensive understanding of the electrolysis process. This means both the growth and the wear of the passivation layer are essential to ELID-grinding. This paper mainly focuses on its growth.

2. Electrolytic passivation of the grinding wheel

At the beginning of the electrolytic dressing process, the interfaces between the pure metallic wheel, the electrolyte and the external electrode are characterized by a high capacitance due to the presence of a double layer on each metallic electrode. Once the wheel is covered with a small passivating layer the capacitance of this electrode is much lower because the charge cannot move freely in the oxides and hydroxides. Subsequently, as dressing continues, the growth of the layer leads to an increase in electrical resistance in the system. The electrolytic current drops and the dissolution of the wheel slows down until full passivation is realized.

2.1. Current and voltage behavior during pre-dressing

This experiment is carried out for a duration of 25 minutes and the settings of the power supply, a Fuji ELIDer 921 which generates chopped voltage pulses, are set at a voltage of 90 V, a peak current of 40 A and a duty ratio of 50%. Table 1 lists the process parameters during this pre-dressing experiment. The CIB wheel has a diameter of 225 mm, a thickness of 15 mm and holds diamonds of 46 µm. The electrolyte is a 2% dilution of Noritake Cool CEM and has a pH value of 9.3 and a resistivity of 5.8 Ωm. The gap width measures 0.25 mm and the wheel speed is 20 m/s.

| Table 1: Process parameters during pre-dressing experiment |
|-----------------------------------------------------------|
| Grinding wheel CIB – D46, Ø 225 mm, b = 15 mm           |
| Electrolyte 2% Noritake Cool CEM + demineralized water |
| Gap width 0.2-0.25 mm                                    |
| Power supply Fuji ELIDer 921: V = 90 V, Ip = 40 A, Rc = 50% |
| Wheel speed 20 m/s                                      |

Figure 2 shows the evolution of the average current and voltage during the pre-dressing phase. As can be seen in this figure the average current drops while the average...
voltage rises. The current starts at 10 A in average (given the duty cycle of 50%, the peak current is about 20 A) and the initial mean voltage measures less than 20 V. The injection electrode covers the wheel for an angle of 60° and the current flows through an area of about 20 cm² of the wheel surface. Therefore the initial current density is about 0.5 A/cm². After 25 minutes of dressing the mean voltage is a little over 70 V and the current has dropped to less than 2 A, giving 0.1 A/cm². As current and voltage still change slowly at this stage, there exists a trend towards further passivation, but the effect becomes smaller in time.

2.2. Electrical equivalent model of pre-dressing

In the case of a voltage controlled source, it is expected that the voltage remains constant while the current drops because of the resistance gain during dressing. However, Figure 2 indicates a different behaviour. The explanation for this phenomenon can be found in the electrical equivalent of the passivation layer, which essentially is an electrochemical double layer. As reported in [3] and [4] the passivation layer can be represented by a capacitor $C$ in parallel with a resistor $R_p$, with a second resistor $R_s$ in series. Figure 3 shows the scheme of this Helmholtz representation of a double layer. These three electrical elements slowly change during the electrolytic dressing process.

![Figure 3: Helmholtz representation of double layer](image)

After a certain time of dressing, a passivation layer starts to grow on top of the metallic grinding wheel. Considering the electrical equivalent model this means that the capacitor decreases while both resistors increase. Afterwards this layer is densified and the total resistance keeps on rising. This has been shown experimentally in [4] where the values of the electrical elements are calculated from the pulse shapes for dressing experiments on small pieces of wheel bonding material.

Figure 4 depicts the instantaneous pulses of the experiment in Figure 2 at four different times: after 0.1, 1, 5 and 20 minutes. After 0.1 minute the wheel is covered with a negligible amount of oxides and the parallel resistor is very small. Although the capacitance is big, the small $R_p$ (at least compared to $R_s$), gives rise to a steep voltage drop. The voltage only reaches 37 V, which means that a big part of the supplied voltage is being consumed by other resistors inside the electrical circuit. After 1 minute of dressing the voltage pulses start to float. This is because the voltage drop is less steep than before: a part of the voltage is dissipated through the capacitor and the parallel resistor, causing an exponential decay of the voltage. The voltage decreases more slowly, but also the tops of the voltage pulses reach higher values. The resistors $R_s$ and $R_p$ start to grow and the maximum voltage difference measured between the electrodes gets more and more significant in time. The total resistance $R_t$, which is equal to the sum of $R_s$ and $R_p$, is the key parameter to monitor the process and is calculated from the pulses by using Ohm’s law. After 0.1 minute $R_t$ is 2 Ω, after 1 minute it is 3 Ω, while after 5 minutes it becomes 9 Ω and at 20 minutes it reaches 25 Ω (see also Figure 5). A more detailed explanation on the evolution of the electrical equivalent model during dressing can be found in [4].

3. Dressing experiments

The required time for the passivation of the grinding wheel differs depending on the dressing parameters. To investigate this several experiments have been carried out while measuring the change in voltage and current over time.
3.1. Effect of the power supply settings

The influence of the power supply settings is illustrated in Figure 5. The electrolyte is a 2% dilution of Noritake Cool CEM and the wheel has a cast iron bonding meshed with abrasives of 46 µm. The wheel speed is set at 10 m/s. After each experiment the wheel was cleaned with an abrasive stick to remove the oxide layer. The initial resistances $R_0$ of all experiments lie very close to each other, i.e. in between 1.1 and 1.6 Ω. With this resistance value, the resistivity of the fluid $\rho$ (which is measured to be 3.2 Ωm for this experiment) and the electrode area $A$, the theoretical gap width $l_g$ can be calculated using formula (1).

$$ l_g = \frac{R_0 A}{\rho} \quad (1) $$

This gives a theoretical gap width of 0.67 to 0.98 mm, which is very large. The gap width is set mechanically at a value a little larger than 0.2 mm. However, it is difficult to maintain a constant gap width over the electrode circumference, mainly due to the wear of the wheel. Therefore the effective dressing area is smaller than the theoretical one, which explains the high values resulting from formula (1).

Initially the resistance grows in a random way, independently of the power supply settings. After 25 minutes the resistance is the biggest in the case of the highest power settings, i.e. 90 V, 40 A and 70%. This
means that even for the highest current values the wheel does not simply dissolve, but passivation still occurs. Faraday’s law of electrolysis states that the dissolved volume of a metal is proportional to the charge passed through it. However, during the first 15 to 20 minutes it is possible to find some illogic trends. This is because the layer formation happens very locally and therefore not always in a deterministic way. The initial oxide layer growth is characterized by random effects such as the local gap width and the distribution of the diamonds in the wheel bonding. Secondly, it is not clear what happens exactly in the power supply when the settings are changed. The final resistance values range from 17 to 32 Ω. However, the longer the dressing continues, the better the resistance behaves according to Faraday’s law.

3.2. Effect of the abrasive size

The same experiment was repeated on a grinding wheel with an averaged diamond size of 2.5 µm. The rise in $R_t$ is depicted in Figure 6. Although the initial resistance values are comparable to those of the 46 µm grit sized wheel as shown in Figure 5, in the first 5 minutes little change is observed in $R_t$. After some minutes the resistance begins to rise considerably and this starting time depends on the parameter settings. By comparing Figures 5 and 6 it becomes clear that it takes more time to passivate a wheel with a finer mesh. A possible explanation is that it becomes easier to form a starting layer of oxides when big abrasives are present, because they form some kind of anchor points for the oxides to adhere to.

Figure 6 shows a clear distinction in layer resistance for the different parameters and the results are more consistent to Faraday’s law than those from the previous experiment.

3.3. Effect of the wheel speed

The electrolysis speed strongly depends on the wheel speed. Figure 7 shows the same experiment as in Figure 6, except that the cutting speed is set at 20 m/s instead of 10 m/s. At higher speeds more of the dissolved ions are splashed around due to the centrifugal force and fewer ions will be oxidized, so it is harder to form a passivation layer. The current efficiency of the precipitation is lower and it is believed that a layer of air is trapped on the wheel at high grinding speeds. Strangely it seems that at 90 V, 40 A and 70% the layer growth is similar to the one at 10 m/s with the same settings. For the other settings it takes a longer time for passivation to start. A wheel speed higher or equal to 20 m/s is typically used for ELID-grinding, while a lower speed is preferable for the pre-dressing phase.

3.4. Use of a different type of electrolyte

In the final experiment a commercially available grinding electrolyte was used instead of the typical ELID-fluid of Noritake. This fluid was promoted as an alternative ELID-fluid and has a comparable pH value of 10.5 and resistivity of 8.1 Ωm. The wheel with the 46 µm diamonds is used and the speed is 10 m/s. These are favorable parameters for fast passivation according to the previous experiments. Figure 8 shows that the current flowing through the loop has little effect on the total resistance, both for the highest and the lowest power settings. After 25 minutes of dressing the pulse shapes remain quasi identical to those in the beginning. Although visibly a layer of rust is covering the wheel, the charge consumed in the process mainly leads to dissolution of the grinding wheel. This means that this electrolyte contains too few oxidizing substances to form a proper passivation layer.


4. Conclusions

The Helmholtz representation of a double layer can be used to model the passivation layer growth during the dressing of a metal-bonded grinding wheel. The dressing/passivation speed is faster in the case of higher power outputs, bigger grit sizes and lower wheel speeds. This means that lower wheel speeds are favorable during pre-dressing. Finally, in order to achieve a proper passivation and to avoid wheel corrosion, it is important for the electrolyte to contain the right oxidizing substances. A commercially available grinding electrolyte is shown not to be suitable for this process.

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Figure 7: Pre-dressing of a 2.5 µm grit wheel with Noritake Cool CEM electrolyte at a speed of 20 m/s

Figure 8: Pre-dressing of a 46 µm grit wheel with a different electrolyte at a speed of 10 m/s

“Gecontroleerd ELID proces voor efficiënt en schadevrij slijpen.”