Wire Electrical Discharge Truing of Metal Bond Diamond Grinding Wheels

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Abstract

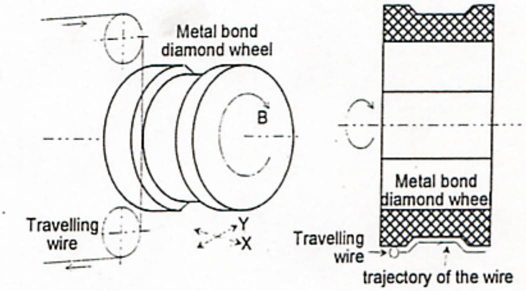
Cylindrical wire EDM profile truing of the metal bond diamond wheel for precision form grinding of ceramics is presented in this report. First a corrosion-resistant, precise spindle with the high-electrical current capability for wire EDM truing of grinding wheel was fabricated. An arc profile was adopted in order to determine form tolerances capabilities of this process. Results show the wire EDM process can generate μm-scale precision form on the diamond wheel efficiently. The wheel, after truing, was used to grind silicon nitride. Grinding forces, surface finish of ground components, and wheel wear were measured. The EDM trued wheel showed a reduction in grinding force from that of the stick dressed wheel. Surface finishes between the two truing methods were similar. In the beginning of the grinding, significant wheel wear rate was identified. The subsequent wheel wear rate stabilized and became considerable lower.

1. Introduction

As the applications of engineering ceramics broadened, the shape of these parts has become more complicated and the form tolerance specifications are more stringent [1]. An efficient and cost-effective method to grind a ceramic component with a complicated shape is to generate the desired form on a diamond grinding wheel and then plunge the shaped wheel into the ceramic workpiece. Based on this approach, the technical challenge has shifted from grinding the workpiece to shaping or truing the diamond grinding wheel. This study investigates the wire Electrical Discharge Machining (EDM) as a process for truing of a metal bond diamond wheel.

Traditionally, a stationary or rotary diamond tool is used to true a grinding wheel to generate the desired form. Shih [2] has studied the wear of the rotary diamond tool for truing of a vitreous bond diamond grinding wheel and demonstrated that the wear of diamond tool is significant under a wide range of process parameters. Instead of using the mechanical force to break the diamond, the wire EDM process uses the thermal energy or electrical sparks between a thin, traveling wire and the rotating grinding wheel to remove the bond around the diamond. Three popular grinding wheel bonding systems are: metal, resin, and vitreous. The EDM process requires the workpiece, in this case the grinding wheel, to be electrically conductive, thus a metal bond wheel is selected.

The configuration of Wire Electrical Discharge Truing (WEDT) process is illustrated in Fig. 1(a). The relative motion between the grinding wheel and traveling wire is controlled by the X and Y slides in a two-axis wire EDM machine to generate the intricate form on a rotating metal bond diamond wheel. Top view of the trajectory of the wire and the form generated on the wheel is shown in Fig. 1(b). Besides the wire EDM, the die-sinking EDM can also be used for truing the metal bond diamond wheel [3]. The literature survey found a lack of research studying the use of the wire EDM method to create μm-level truing of metal bond wheel. Nor was there any data on the EDM trued wheels grinding performance. These become the objectives of this research.



(a) (b)

Fig. 1. Wire EDM of metal bond wheel, (a) configuration of the operation, (b) top view of the trajectory of the wire.

2. Spindle Design

Due to corrosive environment of the EDM process, a corrosion resistant and precise spindle suitable for truing the metal bond grinding wheel was constructed. Spindle runout was reduced to sub-μm level by precise fabrication. Ceramic bearings were used to support the shaft to assure no EDM erosion of the bearings. To transfer the heavy current flow from the spindle shaft to the shaft housing, a shunt carbon brush was used. A DC motor was selected due to good voltage speed control. In order to smoothly transfer rotation from the motor to the spindle shaft a ¼ " round grooved polyethylene pulley and belt was employed. A

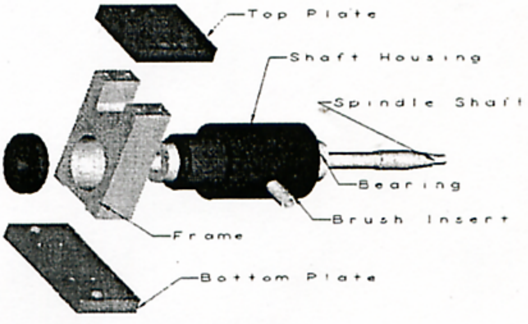


Fig 2. Assembly drawing of the spindle used in WEDT.

standard grinding adapter was used to mount the wheel to the spindle shaft. The shaft's final taper was ground in after assembly was complete. The spindle was placed on a sine table to the desired taper angle, and the spindle's motor was used to rotate the shaft to ensure concentricity.

3. Achievable Form Tolerance

The ability to create a precise form into the grinding wheel was the goal of WEDT. In order to quantify the level of precision achievable, an arc profile was adopted. This form has two arcs of radii 0.665mm and 1.05mm as shown in Fig 3. First the 1200-grit bronze bond diamond grinding wheel was profiled to shape using the WEDT process. Then a piece of machineable plastic was ground. In order to see how the form errors change after an initial grind, a piece of zirconia was ground followed by another piece of machineable plastic.

The two plastic profiled cylinders were then measured for form error using a Rank-Taylor Talysurf machine, with a 0.5mm ball stylus. The data from the arcs where then passed through one of two filters with cutoff values of 0.08mm and 0.25mm. The results are shown in Table 1. These form error values, W_t , are recorded as the peak-to-valley values after the appropriate filtering. From these values two trends are noted; first the form error of the large arc is nearly double that of the smaller arc, secondly the form error decreases after the grinding of the zirconia for both arcs. The reason for the reduction in form error after initial grinding was studied using Stereo-SEM. The results showed that some of the diamonds in the "as trued" wheel surface were protruding nearly half of their size. However, after only a slight presence of force in grinding these diamonds are fractured to a height which can support the load during grinding [4].

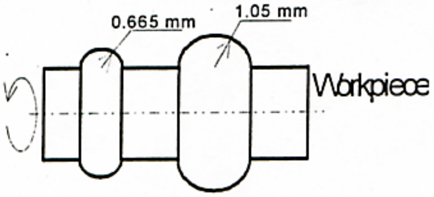


Fig 3. Arc profile used for measuring form error capabilities of the WEDT process.

Table 1. Results of form error measurement.

Table of Form Error		Before Grind		After Grind	
Large Arc	*Cutoff (mm)*	*0.08*	*0.25*	*0.08*	*0.25*
(1.05 mm rad)	W_t (μm)	11.69	9.16	10.45	6.25
Small Arc	*Cutoff (mm)*	*0.08*	*0.25*	*0.08*	*0.25*
(0.665 mm rad)	W_t (μm)	5.45	3.47	1.69	1.07

4. Grinding Study

A grinding study was developed to compare the performance of the WEDT wheel against a single point diamond trued and stick dressed wheel. The single point dressing parameters where; truing tool feed was 5 μm/pass, traverse speed of 127 mm/min, wheel speed of 20 m/s. After the wheel was trued it was then dressed using a 220 grit silicon carbide stick. This will remove some of the metal matrix from around the diamond for chip clearance. With WEDT the truing and dressing were performed simultaneously, thus no stick dressing was required

Once the wheels were prepared, silicon nitride tiles from Toshiba (TSN-10) were ground. The samples are 42.5 mm long (along direction of table feed) and have a width of 6.35 mm. The width of the wheel is 12.7 mm, enabling wheel wear data to be collected. The sample was aligned to the middle of the wheel leaving ungrounded areas near both edges of the wheel. As the parts are ground a groove will be created into the middle of the wheel due to wear. This groove from the wheel can be transferred to create a step into a plastic wear block. This step on the wear block can be measured to determine the progressive wear of the wheel.

The grinding machine was the ELB BD10 with 22.4 kV ball bearing spindle and ball screw slide. The coolant was TRIM 413A with 5% concentration. The 8 inch diameter Norton Scepter diamond wheel (ME 178393 D-2-MX876D-1/4) at 36.6 m/s surface speed was used. The table speed was 127 mm/min, depth of grind was 3.81 mm, specific material removal rate was 8 mm^2/s with 1.03 cm^3 of silicon nitride removed per pass. After each grinding pass through the silicon nitride, a pass was also taken trough the plastic wear block. In addition, the silicon nitride samples were replaced after each pass, in order to measure any changes in surface finish of the samples.

4.1 Forces

Grinding forces were captured in the vertical and horizontal directions using a KISTLER 9257B 3-axis force dynamometer. Spindle power was also measured using a Hall-effect power sensor which was installed on the ELB grinder. A DC voltage output signal from the sensor is given relative to the spindle load, which is then converted to power by a calibration constant. The output signal was passed through a low-pass RC filter, with cutoff frequency of 442 Hz.

As mentioned previously the horizontal and vertical forces were measured during grinding. However, as shown in Fig 4 these forces are not the same as the tangential and normal forces, respectively, due to the large arc of machining caused by a deep depth of cut. As the depth of cut, (t), increases the tangential and normal forces begin to slide up the machining arc.

Tangential force, as the name implies, is the force that is tangential to the wheel's surface. Torque on the wheel is the product of tangential force and wheel radius. Likewise, spindle power load on the wheel is the product of torque and angular velocity. By having the power (P_s), an the horizontal force (F_h), and vertical force (F_v) known, the tangential (F_t) and normal forces (F_n) can be calculated. Since the resultant force of the vertical and horizontal forces is the same as that of the tangential and normal forces, the relationship can be made that:

$$\left[F_n^2+F_t^2\right]=\left[F_h^2+F_v^2\right] \qquad (1)$$

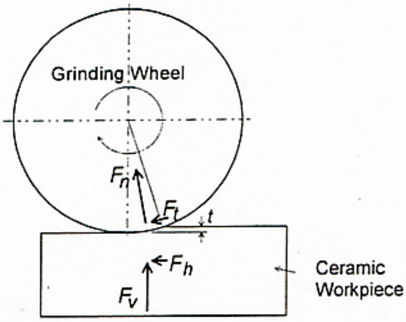


Fig 4. Diagram of grinding forces for deep DOC.

Then, the tangential force is just the spindle load divided by the wheel surface speed (V_s).

$$F_t = \frac{P_s}{V_s} \tag{2}$$

By rearranging Eqs. (1) and (2) the normal force can be calculated.

Fig 5 shows the tangential and normal force results after the conversion. Notice that the EDM wheel has tangential forces that are 20% lower than that of the stick dressed wheel. This remains the case until the sixth pass, where the stick dressed wheel begins to break down. The forces produced by the stick dressed wheel began to increase drastically, which causes the diamonds on the surface to fracture or pull out, which is known as wheel breakdown. This also occurred with the EDM trued wheel, but after 15 passes.

Normal forces generated when grinding with the traditionally dressed wheel are also 20-40% higher than forces produced when grinding with the EDM trued wheel. On the sixth pass, the normal force reached nearly 800 N for the traditionally dressed wheel. While on the eighth pass, the EDM wheel was only seeing forces around 500 N.

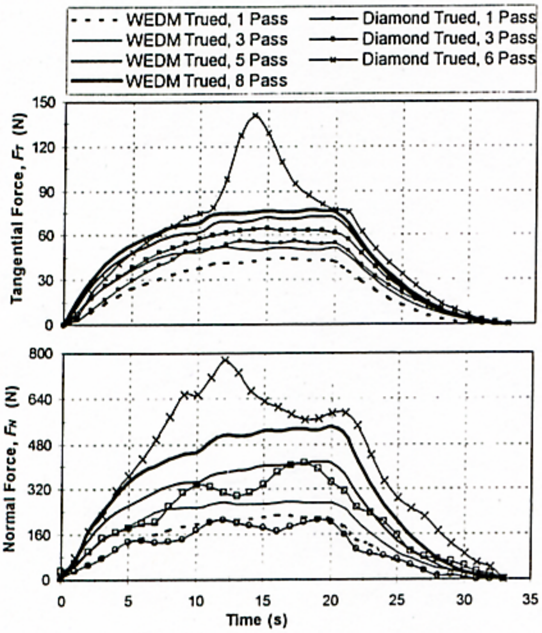


Fig 5. Forces generated during silicon nitride grinding.

4.2 Surface Finish and Wheel Wear

Since the samples were removed after each pass, they were measured to establish surface finish trends. The measurements were made using a Talysurf machine with a standard diamond 2 μm radius tip, and a 0.25 mm cutoff.

The results in Fig 6 show that both truing methods produce components of similar roughness. The peak-to-valley roughness is an order of magnitude greater than the average roughness, which was expected. As the wheel is continually used the surface finish of the components improves. This can be ~~co~~ntributed to an increase in the diamonds' wear flat.

The depth of the groove created in the wheel, due to wear, is also shown in Fig 6. An initial high wear rate, shown by the slope of the line, is noted for both truing methods. However, after the first pass both wheels seem to stabilize at the same wear rate, or have the same slope. The higher initial wear rate of the EDM trued wheel was determined to be caused by fracturing of over-protruding diamonds on the wheel surface [4]. It was also noted that form error was not increased due to diamond fracture, since the form is placed in the metal matrix and not in the

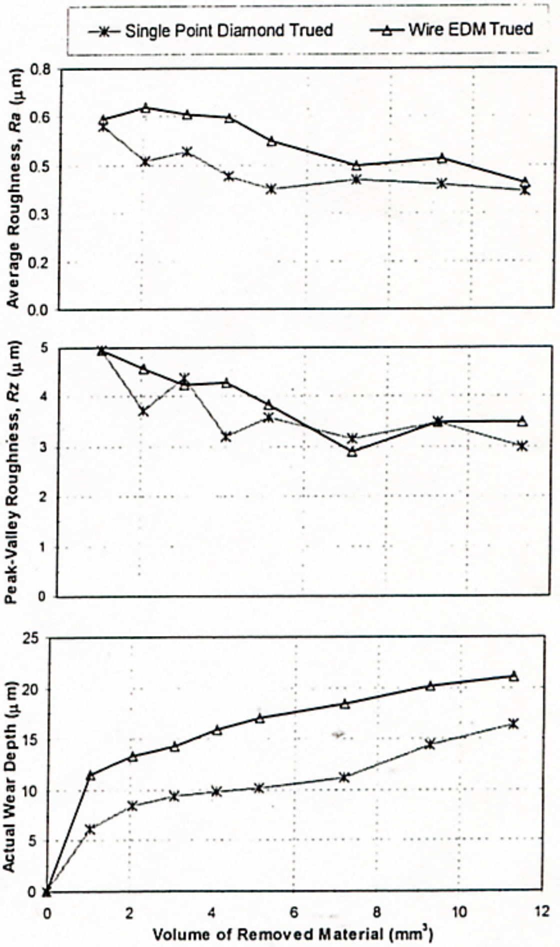


Fig 6. Surface finish of ground silicon nitride samples and wheel wear during grinding.

diamonds themselves.

5. SEM Investigation of Wheel Wear

Stereo SEM was used to study the high initial wheel wear rate of the EDM trued wheel. Fig 7 shows a diamond that is protruding from the EDM trued wheel surface about 29 µm. All of the diamonds measured in WEDT surface were in the range 3-35 µm. The size of the average diamond in this wheel is about 60 µm.

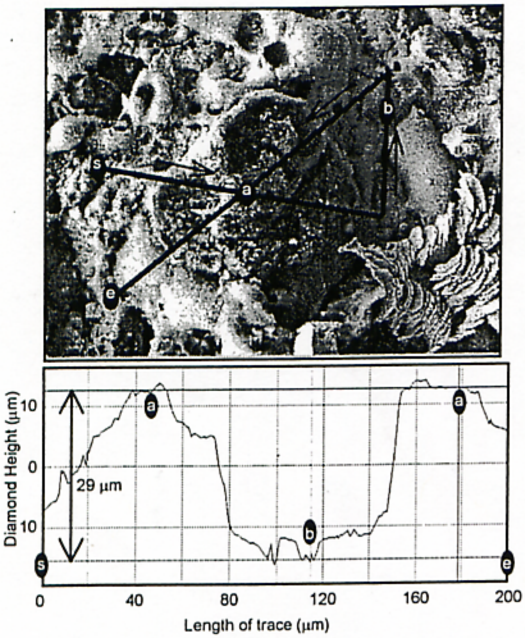


Fig7. Stereo-SEM profile of WEDT virgin wheel surface.

A section of the same wheel was used to grind silicon nitride. A single light pass was used to determine the diamond height after only a slight presence of grinding force. The results show that those forces reduced the diamond height range to 3-13 µm.

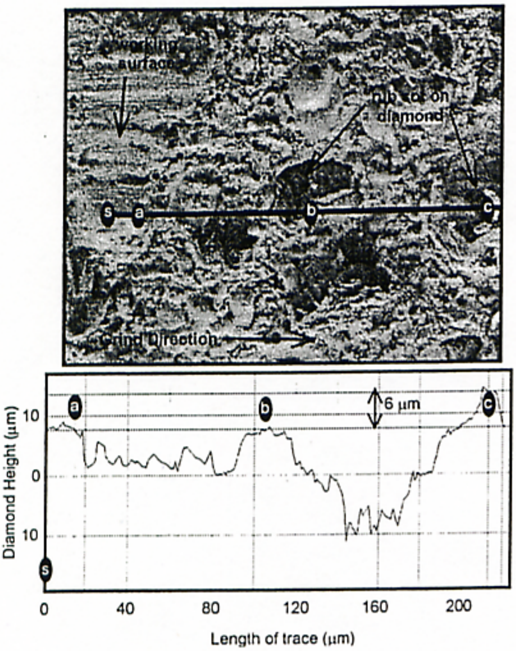


Fig 8. Stereo-SEM profile of lightly ground wheel surface.

Fig 8 shows two diamonds that are active, as seen by the rub marks on top of the diamonds. The Stereo SEM reveled that the diamond (b) is at the same height as the working plane, while diamond (c) is 6 µm above the working plane. Fig 9 shows a diamond in the lightly ground surface, which appears to have fractured. This is evident by the sharp edges on the diamond surface. Thus the high initial wear rate is due to over protruding diamond fracture, which does not affect the form error.

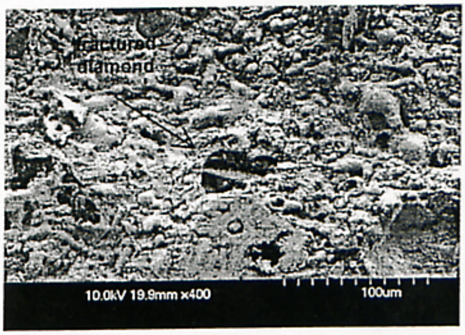


Fig 9. SEM scan of lightly ground wheel surface.

Conclusions

The Wire Electrical Discharge Truing (WEDT) is capable of producing µm-level precision forms in metal bonded super-abrasive wheels. WEDT wheels have reduced grinding force as compared to a stick dressed wheel. WEDT wheels are capable of delaying wheel breakdown, which increases the interval for which redressing is required. The surface finish of components ground with a WEDT wheel are similar to those ground with a stick dressed wheel. Wheel wear rates of the EDM trued wheel stabilizes after the initial introduction of grinding forces. This was due to fracturing of over protruding diamonds on the wheel surface. It was noted that this diamond fracture did not increase the form error, since the form was placed in the metal matrix by spark erosion and not the diamonds themselves.

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