ELECTROCHEMICAL FORM GRINDING

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Final Report
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Prepared by R. W. Stiles

Electrochemical form grinding cutting tests were performed on 25 17-4 PH stainless steel bars by a copper resin aluminum oxide wheel formed from a diamond form block. Tests investigated methods of dressing a form into a grinding wheel, nozzle design, optimum machine settings, and tolerance capabilities. The electrolyte was distributed evenly onto the wheel by a form-fitting nozzle, and a minimum of two passes, rough and finish, were made because of current density variations throughout the cut. Tolerance held on the form test samples was ± 0.12 mm on the contour, with an average 0.12 mm overcut.

DK/drb

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SUMMARY

Cutting tests were performed on stainless steel test bars to evaluate electrochemical form grinding. Methods of dressing a form into a grinding wheel, nozzle design, optimum machine settings, and tolerance capabilities were investigated during this study.

A diamond form block was purchased to form a copper resin aluminum oxide wheel and 25 test blocks were ground. Two passes were made to produce the desired configuration. The tolerance held on the form of the test samples was ± 0.12 mm on the contour, with an average overcut of 0.21 mm.

Metal bond and copper resin bond wheels in both diamond and aluminum oxide are available. The copper resin aluminum oxide wheels are easily formed and are the most adaptable type for form grinding. The wheel diameter should be as large as the machine can accommodate to provide better grinding speed, accuracy, and electrolyte flow.

The electrolyte must be evenly distributed with a form-fitting nozzle onto the wheel. A minimum of two passes must be made in electrochemical form grinding because of current density variations occurring throughout the cut, particularly on the initial pan.

This report concludes a three-part study in electrochemical grinding. No further activity is planned.

DISCUSSION

SCOPE AND PURPOSE

Cutting tests were performed on 17-4 PH stainless steel test bars with a formed grinding wheel to evaluate electrochemical form grinding. Methods of dressing a form into a grinding wheel, nozzle design, optimum machine settings, and tolerance capabilities were investigated during this study.

PRIOR WORK

This report concludes a three-part study of electrochemical grinding (ECG).

The first phase¹ involved tests performed on an electrochemical surface grinder to establish overcut, dimensional-variation, parallelism, flatness, and surface-finish guidelines for the electrochemical grinding of 17-4 PH stainless steel, 303 Se stainless steel, and 6061-T6 aluminum. Based on this study, the following process standards were developed.

- Tolerance for large areas was $\pm 50.8 \mu\text{m}$; for small areas, $\pm 2.54 \mu\text{m}$.
- The surface finish was 0.3 to $0.8 \mu\text{m}$.
- Metal removal consisted of rough and finish cuttings for large areas. Material in small areas was removed in one pass.
- Current density of stainless steel was 1.55 to 3.10 A/mm^2 ; of aluminum, approximately 1.55 A/mm^2 .
- Voltage for rough cuttings on stainless steel was 7 to 8 V; for finish, 4 to 5 V. Voltage for rough cuttings on aluminum was 5 to 6 V; for finish, 2 to 3 V.

The second part involved the study of slotting by electrochemical grinding. The tolerance capabilities are summarized below.²

- Tolerance for the copperbond Al_2O_3 wheel was $\pm 96.52 \mu\text{m}$; for the diamond wheel, $\pm 106.68 \mu\text{m}$.
- Overcut for the copperbond Al_2O_3 wheel was $20.00 \mu\text{m}$; on the diamond wheel, $32.00 \mu\text{m}$.

- Taper on the copperbond Al_2O_3 wheel was 60.96 μm ; on the diamond wheel, 99.06 μm .
- The depth of cut on the copperbond Al_2O_3 was 20.32 mm each pass, but the wear rate was so great that a tolerance could not be established. On the diamond wheel, the depth of the cut was 40.64 μm .
- The fillet radius for the copperbond Al_2O_3 wheel was 55 percent of the width; for the diamond wheel, the radius was 41 percent of the width.
- The feed rate for both Al_2O_3 and diamond wheels was 1.27 mm/s.
- The voltage setting for both Al_2O_3 and diamond wheels was 3 V.

ACTIVITY

Grinding wheel material selection and method of forming the wheel, wheel size, electrolyte application, and depth of cut all influence electrochemical form grinding.

Wheel Material and Method of Forming

The various types of grinding wheels available that can be used in electrochemical form grinding are metal bond diamond and non-diamond wheels, and copper resin bond diamond and non-diamond wheels.

The metal-bonded wheels, both diamond and non-diamond, are machined to the desired shape. A single layer of abrasive is then deposited on the wheel periphery. If the user does not have a trueing wheel to reshape the form grinding wheel, it must be sent back to the manufacturer for reforming.

The copper resin diamond wheels have a diamond layer 3.18 mm thick. These wheels also have to be preformed to the desired contour by the wheel manufacturer. The advantage of the copper resin wheels is that they can be retrued many more times than the metal wheels. However, these wheels are limited to fairly simple shapes.³

The copper resin aluminum oxide grinding wheels can be formed fairly easily by the operator, with a diamond radius dressing attachment or diamond form block on the machine. Dressing rates with a single-point diamond should be 0.012 to 0.025 mm for each pass.

Use of a diamond form block requires reversing the polarity of the power supply to convert the wheel to an anode. When the diamond-faced block is brought into contact with the wheel, the metallic bond of the wheel is eroded electrolytically, while simultaneously the abrasive grain in the wheel is dressed to the desired shape by the diamond particles in the block.

Wheel Size

The grinding wheel should be as large in diameter as can be accommodated on the machine. Larger diameter wheels provide greater grinding speed and electrolyte flow.

In electrochemical grinding, the amount of metal removal is approximately proportional to the current passed between the wheel and workpiece. As the area in contact between the wheel and work is increased, the amperage is increased, resulting in greater material removal. Figure 1 illustrates the formula for calculating the contact area.

Therefore, for a 203.2-mm-diameter wheel taking a 2.54-mm-deep cut 12.70-mm wide, the contact area is 289.05 mm^2 , compared with 354.71 mm^2 for a 304.8 mm-diameter wheel.

Another factor in larger diameter wheels is current density changes. Figure 2 illustrates a grinding wheel in contact with a workpiece. Horizontal lines divide the material into equal sections, and vertical lines are drawn at the point of contact of the wheel. The resulting arc lengths relate to the amount of area available on the wheel for passing current to the equal amounts of stock to be removed. At the leading edge of the wheel, only a small area is open for passing current to the work. Conversely, at the bottom of the wheel the area is much larger, even though the amount of material to be removed in both cases is the same. The current density is much higher at the leading edge of the wheel, which results in greater overcut. With a smaller diameter wheel, the current density limit is reached more quickly than with a larger one.

Electrolyte Application

In form grinding, as in all other types of ECG, the electrolyte distribution on the wheel is critical. The electrolyte should be applied through a plastic nozzle that form-fits the wheel. The spinning wheel produces a thin layer of air on its periphery which will prevent the electrolyte from flowing to the wheel. The top surface of the nozzle must fit flush with the wheel to break off the air flow and allow the electrolyte to flow smoothly into the grinding area (Figure 3). This ensures that the wheel is uniformly irrigated and it prevents high wheel wear and arcing damage.

Figure 1. Formula to Figure Wheel Contact Area

Depth of Cut

Taking a full depth of cut in one pass presents a different problem in form grinding than it does in peripheral plunge grinding. As illustrated earlier in this report, current density plays an important role in overcut and tolerance. The higher the current density, the greater the tolerance spread and overcut. Current density is determined by the machining current divided by the contact area (length of arc times width) of the wheel and workpiece. In peripheral grinding the wheel is flat and the length of contact arc is constant across the face. So, on a full depth of cut the current density is constant throughout. In form grinding, however, the cutting curvature in the wheel adds a new dimension; on a full depth of cut, the contact arc will vary at different areas of the wheel, which causes variations in current density throughout the cut and, consequently, differing amounts of overcut. In Figure 4, for a full depth of cut the contact arc varies from S_1 at the deepest part of the cut and S_2 at the shallowest. Arc length S_1 is about three times as long as S_2 , which means that for a given current draw, the current density at S_2 will be about three times higher than S_1 . This will result in uneven overcut

Figure 2. Grinding Wheel in Contact With Workpiece

and an inability to control the desired tolerance throughout the contour. To minimize the problem, a roughing cut should be made on the first pass followed by a finishing cut that is more balanced in the amount of material to be removed. These cuts will make the contact arc more nearly equal throughout the cut.

Cutting Tests

A test situation was set up for electrochemical form grinding to develop the following processing parameters: method on dressing the form into the grinding wheel, nozzle design, optimum machine settings, and tolerance capabilities.

A special design diamond form block was procured (Figure 5). The block was constructed of a metal base with diamonds charged on the surface, and was held in place on the machine magnetic chuck. The polarity of the power supply was reversed, so that the spindle was positive and the diamond form block was negative. The wheel was passed over the block and fed down into the block at a rate of 1.27 mm for each pass. An electrolyte comprised of KCl/KNO₃ was flooded onto the wheel during dressing. The grinding wheel used was a 304.8 mm-diameter by 25.4 mm-wide copper resin bond 100 grit aluminum oxide wheel manufactured by Bay State Abrasives, with the trade name Copperdyne.

Figure 3. Electrolyte Application

After the wheel forming was completed, a plexiglass nozzle blank was driven into the wheel while the wheel was rotating, to contour-fit the nozzle to the wheel.

The test bars were 33.34-mm-square by 25.4-mm-long 17-4 PH stainless steel, and they were held in place during cutting by the machine's magnetic chuck.

The electrolyte was Anocut Solution 90 KCl/KNO₃ mixed with 239.653 kg/m³ of water.

The bars were machined on the cutting tests with a rough and finish pass. About 0.51 mm of material was left for the finish cut. Twenty-five bars were ground to the settings developed for these tests. The ground contour on these bars was measured on an optical comparator to the configuration shown in Figure 6.

For the rough cutting test, which used 8 V and had a feed rate of 0.21 mm/s, the cut depth was 4.6 mm. Machining current was 680 A, and electrolyte flow was 42.0 cm³/s. For the finish cutting test, which used 6 V and recorded a feed rate of 1.27 mm/s,

Figure 4. Contact Arc Variations

the cut depth was 0.51 mm. Machining current was 480 A, and the electrolyte flow was $31.6 \text{ cm}^3/\text{s}$. Table 1 shows the measurements taken on the 25 test bars. Figure 7 shows two views of the nozzle for a grinding wheel.

ACCOMPLISHMENTS

A copper resin bond Al_2O_3 grinding wheel is the most adaptable wheel for electrochemical form grinding.

Because of current density variations caused by cutting curvature of the formed wheel, it is necessary to take at least two passes in electrochemical form grinding.

The test bars ground in this study were roughed to a depth of 4.6 mm at 8 V and 0.21 mm/s feed rate, and finished at 0.51 mm depth of cut, 6 V at 1.27 mm/s feed rate.

Figure 5. Diamond Form Block and Grinding Wheel

The tolerance on the form of the test samples was ± 0.12 mm on the contour. The average amount of overcut experienced on all surfaces was 0.21 mm.

Figure 6. Optical Comparator
Measuring Bar
Ground Contour

Table 1. Measurements on 25 Test Bars
5.08 mm High, 3.18 mm Radius,
and 45 Degree Angle

Part Number	Height (mm)	Radius (mm)	Angle (Degrees)
1	4.97	3.30	47
2	4.99	3.28	50
3	4.85	3.25	48
4	4.80	3.43	46
5	4.88	3.33	45
6	4.93	3.35	44
7	4.87	3.20	47
8	4.95	3.35	49
9	4.81	3.38	46
10	4.90	3.40	45
11	4.82	3.28	44
12	4.80	3.25	43
13	4.83	3.45	47
14	4.96	3.30	48
15	4.95	3.35	47
16	4.88	3.38	47
17	4.93	3.28	46
18	4.99	3.25	45
19	4.80	3.43	46
20	4.85	3.30	47
21	4.87	3.35	46
22	4.88	3.38	48
23	4.95	3.33	46
24	4.70	3.35	45
25	4.81	3.28	44
Average	4.87	3.33	46.24
Standard Deviation	0.07	0.06	1.66

CEMENT ITEMS 1, 2, AND 3 IN PLACE.
TOLERANCES ± 0.38 mm.

Figure 7. Nozzle for a 2.6-Meter-Diameter Grinding Wheel

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