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BRUSH DEBURRING OF MINIATURE PARTS

PDO 6984405, Topical Report

L. K. Gillespie, Project Leader

September 1974

Prepared for the
United States Atomic Energy Commission
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**Kansas City
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Project Leader:
L. K. Gillespie
Department 822

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Topical Report

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BRUSH DEBURRING OF MINIATURE PARTS

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Prepared by L. K. Gillespie, D/822, under PDO 6984405

Brush deburring can produce burr free near-sharp edges on some miniature metal components. A maximum edge radius of 0.002 inch (50.8 μm) is possible; a more practical limit is 0.003 inch (76.2 μm) maximum. Radii with tolerances of 0.003 to 0.005 inch (76.2 to 127 μm) are not producible by brush deburring.

THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

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SUMMARY

Component parts of small mechanisms need near-sharp edges to be reliable, and must also be burr free to avoid jamming of the mechanism if burrs should break loose during operation. In the past, machining burrs have been removed by hand because of these needs, but hand deburring is time consuming and inherently operator variable.

Brush deburring is 1 of 19 processes studied to produce more precise deburring. It is a quick and relatively flexible process and is selective to an edge--that is, it removes burrs while maintaining part size. In addition, brushes can improve surface finish and increase hardness on part edges. This study was initiated to determine which sizes of burrs can be removed and which techniques are needed to produce 0.002 inch (51 μm) maximum and 0.003 to 0.005 inch (76 to 127 μm) tolerance edge radii.

The investigation showed that, under some conditions, 0.002 inch maximum radii can be produced while removing milling burrs. However, as a *general* rule 0.003 inch (76 μm) maximum radii represents the most practical limit to brush deburring capabilities. Radii with tolerances of 0.003 to 0.005 inch do not appear feasible. Producing 0.002 inch maximum radii is physically messy and five to ten times slower than producing a 0.005 inch maximum radius. A skillful operator is also needed. Bendix's conventional brushing techniques can maintain a 0.003 inch maximum radius while removing grinding burrs. Higher spindle speeds or different wheels are required to remove milling burrs or to maintain smaller radii.

While the capabilities described fall short of the total study objectives, it is evident that brush deburring can be used effectively on many less critical components. By using a mechanism which controls the power applied to the workpiece edge an improvement in radiusing capabilities may be obtainable.

DISCUSSION

SCOPE AND PURPOSE

This study determined which brushing techniques would remove typical machining burrs and at the same time produce 0.002 inch (51 μ m) and 0.003 to 0.005 (76 to 127 μ m) corner breaks.

PRIOR WORK

Earlier Bendix deburring investigations explored the capabilities of vibratory deburring, thermal shock deburring, and deburring methods for plastic parts.¹⁻⁶ Extrude hone⁷, electrochemical⁸, and electropolish deburring⁹ have been investigated under this process development. No prior work by Bendix has been reported on brush deburring.

ACTIVITY

Motor driven brushes have long been used for deburring, radiusing, and polishing automotive gears. No published literature was found on power brushing of small parts, size of burr removed, or size of radius produced.

To provide this data both grinding and face milling burrs were produced on five different materials, with feeds and speeds typical of precision miniature parts. The materials studied included 303 Se and 17-4 PH stainless steel, 6061-T6 aluminum, and beryllium copper. Twenty-three brush or wheel types were studied, as were the effects of spindle speed, number of passes, and wheel feed rate.

Power brushing, as used in this study, involves five basic types of wheels: bristle brushes, filled bristle brushes, non-woven nylon abrasive discs, filled non-woven nylon wheels, and cotton buffs coated with abrasive compounds (Figure 1). Abrasive laden rubber wheels were also evaluated in this study.

The filled brushes look like grinding wheels because the voids in the brush are filled with elastomer to support each bristle's wire tip. This produces a harder or more aggressive wheel. The nylon discs are abrasive laden and similar to kitchen scouring pads. Like filled wire wheels, a harder abrasive wheel is produced by filling the nylon discs with an elastomer material.

- A. Natural rubber wheel with impregnated abrasives
- B. Tampico fiber brush treated to hold deburring compound
- C. Cotton buffing wheel
- D. Nylon mesh with abrasive attached to mesh
- E. Natural rubber wheel switch impregnated abrasives, wire brushes, elastomer filler hollow end brush
- F. "Burring" compound used with buffing wheel and tampico brush
- G. Resin filled nylon wheel, 1.5 inch (38.2 mm), nylon bristle brushes with impregnated abrasives
- H. Nylon bristle brush with impregnated abrasives
- I. Resin filled nylon mesh wheels

Figure 1. Brushes and Wheels Used for Deburring

Brush Deburring Versus Brush Radiusing

For several years, hand deburring has used small brushes mounted on small bench motors to radius the edges of miniature parts. The burrs are first removed by knives and files; the brushes remove the sharp edges created by the knives and give a uniform blending. While this technique does produce a high quality part, in general it takes longer to finish a part than would a brush which deburrs and radiuses. Besides faster deburring, brushing eliminates the accidental gouging of edges which occurs with knives.

Limitations Imposed By Workpiece Size and Shape

To reach all edges of a contoured part a non-filled bristle brush must be used, a minor limitation that nevertheless eliminates two-thirds of the wheels which could be used. With large quantities of production parts, though, it is feasible to shape the wheel's bristles to fit the part. Extremely small parts must be fixtured if brush deburring is used. Brushing will typically remove 0.0001 to 0.0002 inch (2.6 to 5.1 μm) stock from the sides of a stainless steel workpiece. Although this stock loss only occurs near the edges, this may be objectionable on very high precision parts. On softer metals, 0.001 inch (26 μm) should be allowed for stock removal.

Side Effects

Three side effects accompany brush deburring. First, wire brushes will harden the workpiece. Kuznetsov¹⁰ found that this surface hardness can be up to five times harder than the parent metal. (Table 1):

Such a high increase in the microhardness shows that it is not caused by the plastic deformation alone because, as shown by experiments, the increase in microhardness due to work hardening can only be just over two-fold. For instance, the maximum hardness of copper due to work hardening is 110 kg/mm², for pure aluminum 40 kg/mm². Consequently, the microhardness of the deformed layer cannot be explained by work hardening alone. *It can be assumed that cleaning with a steel wire brush is causing some chemical reactions which strongly increase the microhardness.*

When a good wear life is desirable, extra hardness may be a major benefit; in fighting metal fatigue, this highly stressed layer may be detrimental.

Table 1. Microhardness of Surface Film and Base Metal

Metal	Surface Film		Base Metal	
	kg/mm ²	psi	kg/mm ²	psi
Aluminum	130	184,900	23	32,714
Copper	180	250,602	55	78,228
Brass	210	298,690	95	135,122
Armco Iron	600	853,400	130	184,900

A second side effect: the use of abrasive-laden wheels and abrasive compounds can be a source of impregnated or contaminating substances. Although no studies have been reported on abrasive impregnation from abrasive laden wheels, most abrasive processes are believed to cause some impregnation, resulting in poor plating adhesion or poor welds. The compounds used with polishing wheels or cotton buffs represent a more noticeable side effect: the adhesive base of some of these compounds is difficult to remove from the workpiece. With proper use and cleaning, neither impregnation nor compound contamination need be a problem.

The third side effect is a condition known as "orange peel". The appearance of this pebbled surface is usually the result of a large and erratic grain structure in the workpiece reacting to brushing forces and heat.¹¹ This can be minimized by heat treating the workpiece to obtain a smaller grain size prior to brushing. (Heat treatment can also make the burr more brittle.) An easier approach is to use more abrasive and less friction in the brushing operation, since the frictional forces rather than the cutting forces appear to be responsible for the "orange peel" effect.

For deburring stainless steel, stainless steel brushes or abrasive-laden nylon brushes should be used to prevent after-rust caused by steel wire.

Results of Brush Deburring Tests on Grinding Burrs

Grinding burrs can readily be removed using 1.375 inch (34.9 mm) diameter brushes and 5000 rpm bench motors. The resulting edge radii can be as large as 0.0186 inch (0.47 mm) on aluminum (Table 2). By appropriate choices of brushes and technique, however, radii of 0.003 inch (76 μ m) maximum can be maintained on aluminum in the burr removal operation (Table 3). A 0.002 inch (51 μ m) maximum radius can also be maintained on 17-4 PH stainless

steel. A statistical analysis of variance indicates that edge radii are affected by feedrate past the brush, number of passes made past the brush, and type of brush as well as workpiece material. In each case there is a unique combination of factors which produces the minimum edge radius. As a general rule, edge radii were roughly proportional to workpiece hardness.

The radii shown in Table 2 result when the effects of brush feedrate and number of passes in front of the brush are ignored. It represents an average value of radius resulting when these two variables are not controlled. The data in Table 3 represents the *maximum* radius produced at the optimum combination of feed-rate and number of passes.

Table 2. Typical Results of Brush Deburring a Grinding Burr

Brush	Workpiece Material									
	17-4PH		303 Se		BeCu		7075-T6		6061-T6	
	(Inch)	(µm)	(Inch)	(µm)	(Inch)	(µm)	(Inch)	(µm)	(Inch)	(µm)
Stainless Steel	0 0064	163	0 0064	163	0 0085	216	0 0174	442	0 0188	472
Nylon with SiC	0 0055	140	0 0064	163	0 0053	135	0 0070	178	0 0082	208
Nylon with AL ₂ O ₃	0 0084	163	0 0058	147	0 0079	201	0 0062	157	0 0066	168
String with SiC	0 0035	89	0 0035	89						
Typical Material Hardness (Brinell)	415		226		187		150		95	
Values shown are edge radii Missing data indicates conditions not tested										

Table 3. Best Case Results of Brush Deburring a Grinding Burr

Brush	Workpiece Material									
	17-4 PH		303 Se		BeCu		7075-T6		6061-T6	
	(Inch)	(μ m)	(Inch)	(μ m)	(Inch)	(μ m)	(Inch)	(μ m)	(Inch)	(μ m)
Stainless Steel	0 0067	170	0 0060	152	0 0030	76	0 0225	572	0 0104	264
Nylon with SiC	0 0055	140	0 0037	94	0 0011	79	0 0050	127	0 0049	124
Nylon with Al_2O_3	0 0030	78	0 0036	91	0 0058	173	0 0017	43	0 0025	66
String with SiC	0 0020	51	0 0036	91						
Values shown represent edge radii in inches which can be maintained on 99.7 percent of the edges finished at optimum conditions Missing data indicates conditions not tested										

The data in Tables 2 and 3 were obtained by feeding the workpiece past the brush at feedrates of 1.0 and 2.0 inch per minute (ipm) (0.67 and 1.34 mm/s). * Half the specimen made one pass across the brush, half made four passes. Parts were brushed with one of four brushes at 3000 rpm. This is considerably below the spindle speed recommended for these 1.375 inch (34.9 mm) diameter brushes, but is compatible with in-house practice and equipment. Brush bristles tested included stainless steel (A1)**, nylon with impregnated silicon carbide (A2), nylon with impregnated aluminum oxide (A3), and string impregnated with silicon carbide (A4).

Four passes across the brush typically produced a larger radius than a single pass. The faster feedrate which results in a shorter time in front of the brush typically resulted in smaller radii (Figures 2 through 6). The stainless steel specimens were an exception to this effect, however: a faster feedrate typically resulted in a larger radius (Figures 3 and 4), an anomaly not readily explainable.

The string brush with impregnated silicon carbide produced the smallest radii. These radii typically varied from 0.002 to 0.004 inch (51 to 102 μ m) in stainless. Typical radii produced by the other three brushes ranged from 0.004 to 0.008 inch (102 to 208 μ m). The exceedingly short life of these brushes (four to eight edges) and their high cost make them impractical for most applications.

Results of Brush Deburring Milling Burrs

Milling burrs can be removed by power brushing. Cotton buff wheels or tampico brushes coated with an abrasive compound produce the smallest radius in a deburring operation: radii of less than 0.001 inch (25 μ m) are possible on aluminum and stainless steel. The repeatability of such small radii is questionable at this time, however. The majority of other wheels studied produced radii of 0.003 to 0.005 inch (76-127 μ m). Because the abrasive compound is manually applied to the cotton buff wheel at the discretion of the operator it is inherently operator variable.

*For this study a contact length (interference) of 0.125 inch (3.18 mm) was used for the stainless steel brushes, and 0.25 inch (6.35 mm) for all other brushes. For optimum brush life, the bristles should just touch the workpiece edge.

**Numbers in parentheses refer to brush description code in appendix Table A1. Tables A2 through A4 contain additional test details and the analysis of variance results.

STAINLESS STEEL BRUSH

A - r = 0.0095	(0.241 mm)
σ = 0.0006	(15.2 μm)
B - r = 0.0082	(0.208 mm)
σ = 0.0010	(25.4 μm)
C - r = 0.0036	(0.91 mm)
σ = 0.0011	(27.9 μm)
D - r = 0.0005	(0.114 mm)
σ = 0.0012	(30.5 μm)

NYLON BRUSH WITH SiC

A - r = 0.0068	(0.173 mm)
σ = 0.0006	(15.2 μm)
B - r = 0.0060	(0.152 mm)
σ = 0.0009	(22.9 μm)
C - r = 0.0059	(0.150 mm)
σ = 0.0037	(94.0 μm)
D - r = 0.0034	(0.086 mm)
σ = 0.0007	(17.8 μm)

NYLON BRUSH WITH Al_2O_3

A - r = 0.0072	(0.183 mm)
σ = 0.0011	(27.9 μm)
B - r = 0.0101	(0.257 mm)
σ = 0.0026	(66.0 μm)
C - r = 0.0055	(0.140 mm)
σ = 0.0021	(53.3 μm)
D - r = 0.0027	(0.069 mm)
σ = 0.0001	(2.5 μm)

STRING BRUSH WITH SiC

A - r = 0.0028	(0.071 mm)
σ = 0.0006	(15.2 μm)
B - r = 0.0014	(0.035 mm)
σ = 0.0002	(5.1 μm)
C - r = 0.0050	(0.127 mm)
σ = 0.0012	(30.5 μm)
D - r = 0.0042	(0.11 mm)
σ = 0.0005	(12.7 μm)

Figure 2. Brush Deburring Results on 17-4 PH Stainless Steel

STAINLESS STEEL BRUSH

A	-	r = 0.0088	(0.224 mm)
		$\sigma = 0.0013$	(33.0 μm)
B	-	r = 0.0074	(0.188 mm)
		$\sigma = 0.0002$	(5.1 μm)
C	-	r = 0.0050	(0.127 mm)
		$\sigma = 0.0012$	(30.5 μm)
D	-	r = 0.0042	(0.107 mm)
		$\sigma = 0.0006$	(15.2 μm)

NYLON BRUSH WITH SiC

A	-	r = 0.0083	(0.211 mm)
		$\sigma = 0.0004$	(10.2 μm)
B	-	r = 0.0064	(0.163 mm)
		$\sigma = 0.0007$	(17.8 μm)
C	-	r = 0.0037	(0.094 mm)
		$\sigma = 0$	
D	-	r = 0.0070	(0.178 mm)
		$\sigma = 0.0002$	(5.1 μm)

NYLON WITH Al_2O_3 BRUSH

A	-	r = 0.0080	(0.203 mm)
		$\sigma = 0.0005$	(12.7 μm)
B	-	r = 0.0024	(0.061 mm)
		$\sigma = 0.0004$	(10.2 μm)
C	-	r = 0.0083	(0.211 mm)
		$\sigma = 0.0018$	(45.7 μm)
D	-	r = 0.0044	(0.116 mm)
		$\sigma = 0.0005$	(15.2 μm)

STRING BRUSH WITH SiC

A	-	r = 0.0048	(0.122 mm)
		$\sigma = 0.0003$	(7.6 μm)
B	-	r = 0.0040	(0.102 mm)
		$\sigma = 0.0001$	(2.5 μm)
C	-	r = 0.0027	(0.069 mm)
		$\sigma = 0.00030$	(7.6 μm)
D	-	r = 0.0023	(0.058 mm)
		$\sigma = 0.0009$	(22.9 μm)

Figure 3. Brush Deburring Results on 303 Se Stainless Steel

STAINLESS STEEL BRUSH

A	-	r = 0.0118	(0.297 mm)
		$\sigma = 0.0012$	(30.5 μm)
B	-	r = 0.0168	(0.426 mm)
		$\sigma = 0.0010$	(25.4 μm)
C	-	r = 0.0027	(0.069 mm)
		$\sigma = 0.0001$	(2.5 μm)
D	-	r = 0.0053	(0.084 mm)
		$\sigma = 0.0002$	(5 μm)

NYLON BRUSH WITH SiC

A	-	r = 0.0080	(0.203 mm)
		$\sigma = 0.0020$	(50.8 μm)
B	-	r = 0.0039	(0.099 mm)
		$\sigma = 0.0005$	(12.7 μm)
C	-	r = 0.0022	(0.056 mm)
		$\sigma = 0.0003$	(7.6 μm)
D	-	r = 0.0069	(0.175 mm)
		$\sigma = 0.0009$	(22.9 μm)

NYLON BRUSH WITH Al_2O_3

A	-	r = 0.0120	(0.305 mm)
		$\sigma = 0.0005$	(12.7 μm)
B	-	r = 0.0107	(0.272 mm)
		$\sigma = 0.0012$	(30.5 μm)
C	-	r = 0.0036	(0.066 mm)
		$\sigma = 0.0014$	(35.6 μm)
D	-	r = 0.0083	(0.160 mm)
		$\sigma = 0.0017$	(43.2 μm)

Figure 4. Brush Deburring Results on 7075-T6 Aluminum

STAINLESS STEEL BRUSH

A	- r = 0.0242 (0.615 mm)
	σ = 0.0019 (48.6 μm)
B	- r = 0.0153 (0.389 mm)
	σ = 0.0037 (94.0 μm)
C	- r = 0.0141 (0.358 mm)
	σ = 0.0028 (71.1 μm)
D	- r = 0.0161 (0.409 mm)
	σ = 0.0011 (27.9 μm)

NYLON BRUSH WITH SiC

A	- r = 0.0101 (0.257 mm)
	σ = 0.0018 (45.7 μm)
B	- r = 0.0049 (0.122 mm)
	σ = 0.0002 (5.1 μm)
C	- r = 0.0047 (0.119 mm)
	σ = 0.0001 (2.5 μm)
D	- r = 0.0083 (0.211 mm)
	σ = 0.0004 (10.2 μm)

NYLON BRUSH WITH Al_2O_3

A	- r = 0.0011 (0.028 mm)
	σ = 0.0002 (5.1 μm)
B	- r = 0.0050 (0.127 mm)
	σ = 0.0007 (17.8 μm)
C	- r = 0.0046 (0.117 mm)
	σ = 0.0004 (10.1 μm)
D	- r = 0.0042 (0.107 mm)
	σ = 0.0032 (81.3 μm)

Figure 5. Brush Deburring Results on 6061-T6 Aluminum

STAINLESS STEEL BRUSH

A - r = 0.0276 (0.701 mm)
σ = 0.0057 (144.8 μm)
B - r = 0.0173 (0.439 mm)
σ = 0.0044 (111.8 μm)
C - r = 0.0089 (0.226 mm)
σ = 0.0006 (12.7 μm)
D - r = 0.0207 (0.526 mm)
σ = 0.0014 (30.5 μm)

NYLON BRUSH WITH SiC

A - r = 0.0100 (0.254 mm)
σ = 0.0010 (25.4 μm)
B - r = 0.0150 (0.381 mm)
σ = 0.0050 (127.0 μm)
C - r = 0.0035 (0.089 mm)
σ = 0.0007 (17.8 μm)
D - r = 0.0043 (0.109 mm)
σ = 0.0002 (5.0 μm)

NYLON BRUSH WITH Al_2O_3

A - r = 0.0021 (0.053 mm)
σ = 0.0004 (101.6 μm)
B - r = 0.0107 (0.272 mm)
σ = 0.0012 (30.5 μm)
C - r = 0.0023 (0.058 mm)
σ = 0.0001 (2.5 μm)
D - r = 0.0113 (0.287 mm)
σ = 0.0012 (30.5 μm)

Figure 6. Brush Deburring Results on Beryllium Copper

Twenty-three brushes or wheels were evaluated on the five materials previously mentioned. For this study, all parts were manually held against the wheel rather than mechanically fed as in the previous test. Face milling was used to produce burrs 0.002 inch thick by 0.0025 inch long (51 by 64 μm) in stainless steel. A 0.0034 inch thick by 0.011 inch long (86 by 279 μm) burr was produced in aluminum.

At 3000 rpm the 1.375-inch-diameter (34.9 mm) brushes used in the grinding burr study were unsuccessful on the stainless steel milling burrs. Although the stainless steel (A1) and the brass (A5) brushes removed the aluminum burrs, the adjacent surfaces were severely eroded. In many cases the metal brushes caused enough plastic flow of the workpiece that a new burr was produced on the part. The use of an abrasive slurry in conjunction with the brushes increased the amount of burr removal but did not totally remove them.

High spindle speeds let the 1.375-inch-diameter brushes remove milling burrs and produce a minimal radius (Table 4). Although the nylon bristle brushes produce small radii at speeds of 25,000 to 45,000 rpm, brush life is short. At speeds of 40,000 rpm the nylon bristles melt on contact with the workpiece if too much pressure is applied; some nylon may solidify on the part. Because of material melting and the noise the very high speeds cannot be recommended at this time. Speeds of 10,000 to 20,000 rpm do provide better deburring, however, than the 3,000 to 5,000 rpm's typically used. Previously published information^{1,2} indicated that speeds above 6000 rpm do not improve the cutting action.

Table 4. High Speed Brush Deburring Results for Milling Burrs

Brush Code	Brush Description	Spindle Speed (rpm)	Number Of Passes	Workpiece Material	Resulting Radius* (Inch) (μm)
A2	Nylon with SiC	45,000	1	303 Se**	0 0010 (25), 0 0012 (30), 0 0015 (38)
A2	Nylon with SiC	45,000	4	303 Se**	0 0010 (25), 0 0006 (15), 0 0008 (20)
A2	Nylon with SiC	45,000	1	6061-T651***	0 0011 (28), 0 0013 (33), 0 0032 (81)
A3	Nylon with Al_2O_3	45,000	2	6061-T651***	0 0054 (137), 0 0114X (290), 0 0113X (287)
A3	Nylon with Al_2O_3	30,000	2	6061-T651***	0 0023 (58), 0 0027 (69), 0 0027 (69)
A3	Nylon with Al_2O_3	30,000	3	6061-T651***	0 0030 (76), 0 0025 (64), 0 0025 (64)
A3	Nylon with Al_2O_3	22,500	4	6061-T651***	0 0043 (109), 0 0034 (86), 0 0069 (175)
*Three measurements were taken at each condition **Stainless steel ***Aluminum					

Cotton buff polishing wheels can be highly effective in removing milling burrs while maintaining sharp edges. To provide the needed abrasive action, the buffing wheel is coated with a thin layer of "burring" compound before use. This combination of an abrasive coating on a soft resilient wheel abrades the burr without noticeably removing stock from the remainder of the part. Typical radii from a freshly dressed wheel can be held to 0.003 inch (71 μ m), as Table 5 shows. By coating a tampico brush with abrasive compound, rather than a cotton buff, a 0.001 inch (26 μ m) radius can be produced (Table 6), but a 0.002 inch (51 μ m) appears to be a more repeatable limit.

The coated buffing wheels and tampico brushes remove very little material from the face of the workpiece. Typically, sides will have a 0.0001 inch (2.5 μ m) taper after deburring the edges (Table 5). The compounds and techniques used for deburring apparently can preserve surface finishes of 12 microinches (0.3 μ m). Edge radii is proportional to time spent in contact with the wheel.

The abrasive coated wheels have disadvantages. Because the wheel is coated with abrasive while the wheel is turning, a considerable amount of media is thrown from the wheel and dirties the work area. Since dressing is done by hand, and the decision to dress is made by the operator, the process is inherently operator variable.* On short runs, cotton buffs are not adaptable to use with sharply contoured parts because they present a flat surface to the part. The tampico brushes coated with the abrasive compounds should be used in these cases.

The majority of techniques studied in these tests produced smooth blends. The abrasive-laden rubberized wheels, however, tended to produce a chamfer rather than a radius (Table 6). This can be minimized by using slow spindle speeds. At high speeds, a stainless steel brush will tend to chamfer or gouge 17-4 PH stainless steel. The coated buffing wheel and tampico brush tend to produce a smaller radius than most other combinations (Tables 5 and 6). Values shown in Tables 5 and 6 are results obtained by an unskilled operator. With experience, 0.003 inch edge radii can be maintained by most of the wheels studied.

*Wheel dressing is itself something of an art. The grease base compounds, which appear to be more effective on burrs than the greaseless, can be applied to a wheel under power. The greaseless compounds must be applied while the wheel is decelerating. An improper choice of bar compound can produce a part which is covered with compound. In some cases, this compound is more difficult to remove than the burr^{12 15}.

Table 5. Brush Deburring of 303 Se Stainless Steel Milling Burrs

Brush Code	Brush	Deburr Compound	Number of Passes	Resulting Radius*		Edge Runout		Finish Near Edge	
				(Inch)	(μ m)	(Inch)	(μ m)	(Inch)	(μ m)
A6	Cotton buff	Stan Sax BB74	1	0.001-0.004	27-102	0.00004	1.0	10	0.25
A6	Cotton buff	Stan Sax BB74	4	0.004-0.007	102-178	0.00015	3.8	8	0.20
A7	Cotton buff	LEA B31	1	0.0013-0.0024	33-61	0.00010	2.5	18	0.46
A7	Cotton buff	LEA B31	4	0.0041-0.0079	104-201	0.00010	2.5	10	0.25
A8	Cotton buff	LEA N	1	0.0020-0.0049	51-125	0.00010	2.5	10	0.25
A8	Cotton buff	LEA N	4	0.0078-0.0100	198-254	0.00010	2.5	12	0.30
A9	Tampico brush	Stan Sax BB74	1	0.0012-0.0016	30-41	0.00020	5.1	6	0.15
A9	Tampico brush	Stan Sax BB74	4	0.0017-0.0018	43-46	0.00015	3.8	9	0.23

*All radii were measured from a permalastic mold of the specimen.
 **Spindle speed was 3450 rpm.

Recommendations

Brush deburring is most effectively used when any of the following conditions exist.

- Deburring and radiusing are required without disturbing part dimensions.
- Workpieces are too large for vibratory deburring.
- Workpiece contours are not readily accessible to vibratory deburring.
- Abrasives cannot be tolerated.
- Parts are too small for vibratory deburring to be effective.
- Radii up to 0.005 inch (127 μ m) are allowable.

As noted before, radii of 0.002 inch (51 μ m) maximum can be produced under some conditions. The repeatability of this small radius has yet to be determined.

In general, workpieces should be fed past the wheel at speeds of 2 inches per minute (0.85 mm/s). To remove grinding burrs with conventional in-house equipment, speeds of 3000 rpm should be used with nylon bristle brushes impregnated with abrasive particles. To remove milling burrs with 1.375-inch-diameter (34.9 mm) brushes, spindle speeds of 10,000 to 20,000 rpm should be used.

Table 6. Selected Results of Brush Deburring of Milling Burrs

Wheel Code Number	Brush	Spindle Speed (rpm)	Workpiece Material	Edge Radii (inch)	(μm)
A9	Wire 0.005 inch bristles, 1.25 inch diameter	22,000	303 Se	0.0032-0.0034	81-86
A7	Cotton buff 6 inch diameter with LEA B31	3,450	303 Se	0.0004-0.0008	10-20
A7	Cotton buff 6 inch diameter with LEA B31	3,450	6061-T6	0.0006-0.0012	15-30
A6	Cotton buff 6 inch diameter with Stan Sax BB74	3,450	6061-T6	0.0008-0.0010	20-25
A6	Cotton buff 6 inch diameter with Stan Sax BB74	3,450	303 Se	0.0034-0.0039	86-99
A10	Tampico brush 2 inch diameter with Stan Sax BB74	15,000	303 Se	0.0006-0.0007	15-18
A11	Cratex 1.5 inch diameter wheel 158-F	15,000	303 Se	0.0017-0.0024	40-61
A11	Cratex 1.5 inch diameter wheel 158-F	15,000	17-4	0.0007-0.0060	18-150
A11	Cratex 1.5 inch diameter wheel 158-F	15,000	BeCu	0.0030-0.0050*	76-127
A11	Cratex 1.5 inch diameter wheel 158-F	15,000	6061	0.0040-0.0062*	102-157
A11	Cratex 1.5 inch diameter wheel 158-F	15,000	7075	0.0029-0.0058	74-147
A12	Ty hollow center end brush	15,000	BeCu	0.0015-0.0016	38-41
A12	Ty hollow center end brush	15,000	7075	0.0044-0.0093	112-236
A12	Ty hollow center end brush	15,000	6061	0.0038-0.0078	97-198
A12	Ty hollow center end brush	15,000	303 Se	0.0015-0.0024	38-61
A12	Ty hollow center end brush	15,000	17-4	0.0009-0.0120	23-30
A13	Fascut 4 inch diameter brush with Stan Sax BB74	3,450	17-4	0.0006-0.0010	13-25
A13	Fascut 4 inch diameter brush with Stan Sax BB74	3,450	303 Se	0.0003-0.0010	8-25
A14	Bear-Tex Unified wheel, 2 inch diameter	11,000	303 Se	0.0011-0.0051	28-130
A14	Bear-Tex Unified wheel, 2 inch diameter	11,000	6061-T6	0.0052-0.0060	132-152
A14	Bear-Tex Unified wheel, 2 inch diameter	11,000	7075	0.0062-0.0071	157-180
A14	Bear-Tex Unified wheel, 2 inch diameter	11,000	BeCu	0.0035-0.0050	89-127
A14	Bear-Tex Unified wheel, 2 inch diameter	11,000	17-4	0.0085-0.0102	215-259
A15	Cotton buff, 6 inch diameter with Stan Sax GL120	3,450	303 Se	0.0031-0.0038	79-97
A16	Bear-Tex JB wheel, 6 inch diameter	3,450	303 Se	0.0031-0.0065	79-165
A16	Bear-Tex JB wheel, 6 inch diameter	3,450	17-4	0.0029-0.0043	74-109
A16	Bear-Tex JB wheel, 6 inch diameter	3,450	7075	0.0095-0.0103	241-261
A16	Bear-Tex JB wheel, 6 inch diameter	3,450	6061	0.0050-0.0105	127-269
A16	Bear-Tex JB wheel, 6 inch diameter	3,450	BeCu	0.0053-0.0061	135-155
*Edge is chamfered rather than radiused All radii were measured from permalastic molds of the brushed specimen.					

If workpiece edges permit and a 0.002 inch (51 μm) maximum radii must be held, a "burring" compound must be used in conjunction with a cotton buffing wheel or a treated tampico wheel. When workpieces are hand size or larger and radii of 0.005 inch (127 μm) and larger are allowable, an elastomer-filled wire wheel or resin filled nylon wheel with impregnated abrasive must be used. Deburring surface speeds for several wheels and brushes were determined (Table 7), and general guidelines formed for selecting brushing conditions (Figure 7).

Figure 7. Guidelines for Improving Brush Deburring

Table 7. Suggested Surface Velocity for Use on Precision Miniature Parts

Wheel Type	For Removing Grinding Burr		For Removing Milling Burr		Typical Radii in 303 Se* After Removing Milling Burr	
	(ft/min)	(m/s)	(ft/min)	(m/s)	(inch)	(μ m)
Stainless Steel Wire with 0.003 inch bristles	800	4.08				
Stainless Steel Wire with 0.005 inch bristles			4000	20.40	0.0035	88
Stainless Steel Wire with 0.008 inch bristles			2500	12.75	0.0050	127
Brass with 0.014 inch bristles	800	4.08				
Nylon with 0.018 inch bristles and Al_2O_3	800	4.08	3500-10,000	28.05-51.00	0.0030	76
Nylon with 0.014 inch bristles and SiC	800	4.08	3500-10,000	28.05-51.00	0.0030	76
String with 0.015 inch bristles and Al_2O_3	800	4.08				
Cotton buff with burring compound	6000	30.60	6000	30.60	0.0030	76
Tampico brush (treated) and burring compound	4000	20.40	4000	20.40	0.0020	51
Rubber with coarse impregnated abrasive						
Rubber with fine impregnated abrasive	500-800	2.55-4.08	800	4.08	0.003	76
Non-woven nylon with impregnated abrasive	8000	40.80				
Non-woven nylon filled with resin and abrasive			8000-10,000	30.60-51.00	0.005	127
Stainless Steel Wire filled with elastomer			2000-4000	10.20-20.40	0.003	76

ACCOMPLISHMENTS

The edge radii produced by 23 brushes and wheels have been documented. Effects on surface finish and dimensions were briefly explored and guidelines for the use of brush deburring have been prepared. While the feasibility of producing 0.002 inch (51 μ m) maximum radii has been shown, the ability to do it consistently has not yet been evaluated.

FUTURE WORK

The repeatability of producing 0.002 inch maximum radii by brush deburring will be studied.

Additional investigations on this process development will study electropolish deburring, centrifugal barrel finishing, extrude hone, and abrasive jet deburring. Studies dedicated to improving hand deburring, burr prevention, and burr size prediction will also be initiated.

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Table A-1. Materials Used

Code Number	Wheel or Brush Type	Description
A1	Stainless Steel Wire	0 003 inch (76 μ m) bristles by 1 inch (25 4 mm) outside by 0 125 inch (3 2 mm) face width
A2	Nylon Bristles	0 014 inch (356 μ m) bristles by 1 375 inch (34 9 mm) outside diameter by 0 25 (6 4 mm) face width Impregnated with 800 grit SiC
A3	Nylon Bristles	0 018 (457 μ m) inch bristles by 1 375 inch (34 9 mm) outside diameter by 0 25 inch (6 4 mm) face width Impregnated with 500 grit Al_2O_3
A4	String	0 015 (381 μ m) inch bristles by 1 375 inch (34 9 mm) outside diameter by 0 25 inch (6 4 mm) face width Impregnated with Al_2O_3
A5	Brass Wire	0 014 inch (356 μ m) bristles by 1 inch (25 4 mm) outside diameter by 0 25 inch (6 4 mm) face width
A6	Cotton Buff	6 inch (152 4 mm) diameter wheel with Stan Sax Corporation grease base bar compound BB74
A7	Cotton Buff	6 inch (152 4 mm) diameter wheel with Lea Corporation bar compound B31 (240 grit Al_2O_3)
A8	Cotton Buff	6 inch (152 4 mm) diameter wheel with Lea Corporation bar compound N (200 grit SiC)
A9	Stainless Steel Wire	0 005 inch (127 μ m) bristles by 1 25 inch (31 8 mm) outside diameter by 0 1875 inch (4 87 mm) face width Osborn Manufacturing Company Ring Lock #2662-SV
A10	Tampico	2 inch (50 8 mm) outside diameter treated tampico (Osborn fascut Ring Lock #2702) with Stan Sax grease base bar compound BB74
A11	Rubber	1 50 inch (38 1 mm) outside diameter by 0 50 inch (12 7 mm) face width rubber wheel impregnated with SiC Cratex #158-P
A12	Stainless Steel Wire	0 005 inch (127 μ m) wire by 0 50 inch (12 7 mm) diameter hollow center end brush filled with an elastomer compound Osborn brush #88 MSV-187-TV
A13		3 inch (76 2 mm) outside diameter treated tampico (Osborn fascut ring lock #2707) with Stan Sax grease base bar compound BB74
A14	Non-Woven Nylon	2 inch (50 8 mm) diameter impregnated with resins and silicon carbide, Norton Coated Abrasives Division Bear-Tex Unified Wheel medium density
A15	Cotton buff	6 inch (152 4 mm) wheel with Stan Sax Corporation greaseless bar compound GL120
A16	Non-Woven Nylon	6 inch (152 4 mm) diameter impregnated with resins and silicon carbide, Norton Coated Abrasives Division Bear-Tex JB Wheel fine density
A17	Non-Woven Nylon	4 inch (101 6 mm) diameter impregnated with resins and silicon carbide, Norton Coated Abrasives Division Bear-Tex FW Wheel, medium density
A18	Stainless Steel Wire	0 003 inch (76 μ m) bristles by 1 inch (25 4 mm) outside diameter by 0 1875 (4 76 mm) face width Osborn Manufacturing Company #2660-SV
A19	Stainless Steel Wire	0 008 inch (203 μ m) bristles by 1 inch (25 4 mm) outside diameter by 0 1875 inch (4 76 mm) face width Osborn Manufacturing Company #2663-SV
A20	Rubber	5 inch (127 mm) outside diameter by 0 375 inch (9 52 mm) face width rubber wheel impregnated with SiC Cratex #506-C
A21	Rubber	5 inch (127 mm) outside diameter by 0 375 inch (9 52 mm) face with rubber wheel impregnated with SiC, Cratex #506-P
A22	Rubber	1 50 inch (38 1 mm) outside diameter by 0 25 inch (6 4 mm) face width rubber wheel impregnated with SiC, Cratex #154-C

Table A-1 Continued. Materials Used

Code Number	Wheel or Brush Type	Description
A23	Wire (Filled)	6 inch (152.4 mm) outside diameter by 0.3125 (7.936 mm) face width, steel bristles, filled with an elastomer material, Osborn Ty monitor brush #3912-SV-Ty
A24	Nylon	6 inch (152.4 mm) outside diameter by 1.50 inch (38.1 mm) face width, nylon bristles are impregnated with 80 grit SiC, Osborn Korfil E brush #38205.

Table A-2. Brushing Results of Edges Having Grinding Burrs

Specimen Number	Brush	Workpiece Feedrate		Number of Passes	Workpiece Material	Resulting Radius (0.0001 Inch) (μm)
		(IPM)	(mm/s)			
1	10207230	2	0.844	1	303	64 (163), 41 (104), 45 (112)
2	↑	2		4	303	74 (180), 75 (180), 71 (180)
3		2		1	17-4	45 (112), 39 (100), 23 (58)
4		2	0.844	4	17-4	69 (175), 78 (198), 100 (254)
5		1	0.422	1	303	43 (109), 36 (91), 49 (124)
6		1		4	17-4	100 (254), 95 (241), 89 (226)
7		1		1	17-4	42 (107), 34 (86), 56 (147)
8		1		4	303	100 (254), 75 (190), 90 (229)
9	10207256	1		1	17-4	31 (79), 43 (107), 28 (71)
10	↑	1		4	303	86 (218), 79 (201), 85 (216)
11		1		4	17-4	67 (170), 63 (160), 75 (190)
12		1	0.422	1	303	71 (180), 68 (173), 71 (180)
13		2	0.844	1	303	37 (94), 37 (94), 37 (94)
14		2		4	17-4	64X (163), 50X (127), 66X (168)
15		2		1	17-4	37X (94), 102X (260), 38X (97)
16		2		4	303	64X (163), 57X (145), 71 (180)
17	10207251	2		1	303	65X (165), 101X (256), 84X (213)
18	↑	2		4	303	28 (71), 20 (51), 25 (64)
19		2		4	17-4	72X (183), 118X (300), 114X (290)
20		2	0.844	1	17-4	35X (89), 54X (137), 77X (198)
21		1	0.422	1	303	48X (122), 47 (119), 37 (94)
22		1		1	17-4	27 (69), 28 (71), 25 (64)
23		1		4	17-4	59 (150), 78 (198), 78 (198)
24		1		4	303	77 (196), 77 (196), 85 (216)
25	10207253	1	0.422	1	303	15 (38), 32 (81), 22 (56)
26	↑	2	0.844	1	17-4	57 (145), 68 (173), 44 (112)
27		2		1	303	28 (71), 24 (61), 30 (76)
28		2	0.844	4	303	41 (104), 38 (97), 40 (102)
29		1	0.422	4	303	47 (119), 52 (132), 46 (117)
30		1	0.422	1	17-4	38 (97), 48 (122), 41 (104)
31		2	0.844	4	17-4	11 (28), 14 (36), 16 (41)
32		1	0.422	4	17-4	35 (89), 25 (64), 25 (64)
33	10207251	2	0.844	1	6061	22 (56), 23 (58), 24 (61)
34	"	2		1	7075	50 (127), 45 (119), 42 (107)

Table A-2 Continued. Brushing Results of Edges Having Grinding Burrs

Specimen Number	Brush	Workpiece Feedrate		Number of Passes	Workpiece Material	Resulting Radius (0.0001 inch) (μm)
		(IPM)	(mm/s)			
35	10207251	2	0.844	4	6061	100X (254), 120X (305), 100X (254)
36	↑	1	0.422	1	6061	100X (254), 120X (305), 120X (305)
37	↑	1		4	7075	10 (35), 13 (33), 10 (35)
38	↑	1		1	7075	200X (508), 27 (69), 200X (508)
39	↑	1	0.422	4	6061	17 (43), 23 (58), 25 (64)
40	↑	2	0.844	4	7075	55 (140), 52 (132), 42 (107)
41	↑	2		1	BeCu	24 (61), 13 (33), 40 (102)
42	↑	2	0.844	4	BeCu	100X (254), 120X (305), 100X (254)
43	↑	1	0.422	1	BeCu	47 (119), 31 (206), 60 (152)
44	10207251	1		4	BeCu	130 (305), 115 (29), 125 (318)
45	10207256	1		1	7075	82 (208), 80 (203), 87 (221)
46	↑	1	0.422	4	6061	90X (229), 100X (254), 111X (282)
47	↑	2	0.844	1	BeCu	10 (48), 25 (64), 23 (58)
48	↑	2		4	6061	200X (508), 150X (381), 100X (254)
49	↑	2		4	BeCu	45 (114), 38 (97), 35 (89)
50	↑	2		1	7075	47 (119), 46 (117), 48 (122)
51	↑	2		4	7075	46 (117), 50 (127), 47 (119)
52	↑	2	0.844	1	6061	29 (74), 42 (107), 35 (89)
53	↑	1	0.422	1	BeCu	48 (122), 100 (254), 59 (150)
54	↑	1		4	BeCu	100 (254), 81 (206), 80 (152)
55	↑	1		4	7075	100 (254), 120 (305), 85 (216)
56	10207256	1		1	6061	43 (109), 45 (114), 40 (102)
57	10207230	1		1	6061	200 (508), 200 (508), 220 (559)
58	↑	1		1	BeCu	33 (84), 35 (89), 31 (79)
59	↑	1		4	7075	250 (635), 255 (648), 220 (559)
60	↑	1		4	6061	340X (864), 232X (589), 255X (648)
61	↑	1	0.422	1	7075	165X (419), 170X (432), 149X (378)
62	↑	2	0.844	1	7075	132X (335), 173X (439), 119X (302)
63	↑	2		4	7075	114X (290), 167X (275), 159X (404)
64	↑	2		4	6061	181X (460), 126X (320), 212X (538)
65	↑	2		1	6061	83X (211), 93X (236), 90X (229)
66	↑	2		1	BeCu	28 (71), 26 (66), 26 (66)
67	↑	2	0.844	4	BeCu	159X (404), 178X (452), 168X (422)
68	10207230	1	0.422	4	BeCu	106X (269), 127X (323), 107X (272)

Table A-3. Factorial Analysis of Variance of Brushing Tests for Stainless Steel, Aluminum and Beryllium Copper Workpieces

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio*
A (Materials)	4	79732	19933	43.57
B (Feedrate)	1	15216	15216	33.26
C (Pass Number)	1	49966	49966	109.21
D (Brushes)	2	98042	49021	107.19
AB	4	13828	3457	7.56
AC	4	27291	6822	14.91
AD	8	105953	13244	28.95
BC	1	3066	3066	6.70
BD	2	4299	2149	4.70
CD	2	24028	12014	26.26
ABC	4	17869	4467	9.76
ABD	8	36729	4591	10.03
ACD	8	28606	3575	7.82
BCD	2	5759	2879	6.29
ABCD	8	27713	3467	7.58
Residual	120	54903	457	
*All F-ratios are significant at the 95-percent level.				

Table A-4. Factorial Analysis of Variance of Brushing Tests for Stainless Steel Workpieces

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio *
A (Material)	1	2	2	.01
B (Feedrate)	1	67	67	.48
C (Pass Number)	1	7921	7921	56.83
D (Brushes)	3	12933	4311	30.93
AB	1	1667	1667	11.96
AC	1	171	171	1.22
AD	3	629	210	1.51
BC	1	3060	3060	21.96
BD	3	1391	464	3.33
CD	3	6431	2144	15.38
ABC	1	247	247	1.77
ABD	3	2287	762	5.47
ACD	3	8357	2786	19.99
BCD	3	1272	424	3.04
ABCD	3	4248	1416	10.16
Residual	64	8920	139	
*Significant at the 95-percent level.				

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