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EXTRUDE HONE DEBURRING
WITH X-BASE MEDIA

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Topical Report

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EXTRUDE HONE DEBURRING WITH X-BASE MEDIA

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

Small precision mechanisms must have burr-free, sharp-edged parts to operate well. Controlling the size of burrs can lower burr removal costs and improve edge repeatability. This study indicated that with conventional tooling approaches, Extrude Hone deburring with X-base media removes more material from the hole than desired and is less repeatable than required on precision miniature parts. With this media, the process is most applicable to precision miniature parts with burrs less than 25.4 μm thick, allowable hole size changes equal to burr thickness, and allowable hole size repeatability of ± 0.2 times the actual average hole size change.

WPC-dvh

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SUMMARY

Component parts for small precision mechanisms have typically required near-sharp edges to assure reliable operation. A burr-free condition is also needed to minimize jamming of the mechanism by burrs breaking off during operation. In the past, reliable removal of machining burrs, combined with protection of the near-sharp edge requirements, has dictated that deburring be done only by hand, which is time consuming and inherently operator variable.

This study was initiated to determine how burr size affected edge radii and stock loss within holes when Extrude Hone deburring was used to remove burrs. The study involved over 3800 measurements and also examined some of the limitations of the process in production situations.

For a given set of Extrude Hone deburring conditions, the final edge radius produced after removing the burr was a function of burr size. Thick tall burrs reduced radiusing action. With standard tooling approaches and Extrude Hone X-base media, removing a $127\text{ }\mu\text{m}$ (0.005 in.) thick by $50.8\text{ }\mu\text{m}$ (0.002 in.) high burr in stainless steel resulted in a $127\text{ }\mu\text{m}$ radii and a $38.1\text{ }\mu\text{m}$ (0.0015 in.) increase in hole size. The same conditions in aluminum resulted in a $190.5\text{ }\mu\text{m}$ (0.0075 in.) radius and a hole size increase of $139.7\text{ }\mu\text{m}$ (0.0055 in.).

Because conventional machining processes produce burrs typically $76.2\text{ }\mu\text{m}$ (0.003 in.) thick by at least $76.2\text{ }\mu\text{m}$ high, it is not possible with standard tooling to remove the burr and maintain an edge radii of $127\text{ }\mu\text{m}$ or less while removing less than $12.7\text{ }\mu\text{m}$ (0.0005 in.) stock from holes. The use of special flow restrictors in the tooling, however, should help maintain such requirements.

Based on in-house production experience, the process is most applicable to parts having burrs $25.4\text{ }\mu\text{m}$ (0.001 in.) thick or less and allowable size changes equal in magnitude to burr thickness. While on the average the process can remove burrs with smaller stock losses, the repeatability of hole size change is in the order of $\pm 25.4\text{ }\mu\text{m}$ for holes 1.58 mm (0.062 in.) diameter or larger.

DISCUSSION

SCOPE AND PURPOSE

The objective of this study was to determine the applicability and limitations of the Extrude Hone deburring process at Bendix Kansas City. Specifically, this study sought to determine some of the limitations of the process in production situations. The effects of the process on hole size change were evaluated for various burr sizes.

PRIOR WORK

The results of a preliminary study on this process have been previously reported.¹

ACTIVITY

Extrude Hone deburring is the process of forcing a "putty" filled with abrasive over burr-laden edges. This pseudo grinding compound quickly wears away burrs and produces a smooth blending radius at edges. Although any viscous putty or carrier could be used to carry the abrasive particles over edges, most of them will grind as much off surfaces as off edges, an undesirable effect on many precision components.

The particular carriers used in the Extrude Hone process have one property that helps accelerate the action at edges: they are *thixotropic*. The significance of this property is that the carrier acts like a solid slug of material as it enters a hole, but once the carrier is moving, it acts more like a liquid. (*Thixotropic* actually implies more than this.) This tends to concentrate the action at the edges. At the initial application of pressure, some of these carriers become very stiff--just as "silly putty" breaks when pulled apart rapidly, but stretches if pulled slowly. This property also accelerates action at edges.

Most of the Extrude Hone carriers have silicone oils in them which could contaminate the electrical components in precision miniature parts. To prevent such an occurrence, Bendix uses Extrude Hone's X-base carrier, a proprietary water base compound which is gelatinous when mixed with water. To provide some rust protection and improve cleaning, four tablespoons of mineral oil are added to the water.

The abrasive most useful in production has been 70-grit particles of black silicon carbide. These particles have an average size of $333\text{ }\mu\text{m}$ (0.0131 in.), but because of the system used to grade abrasives, the particles will range in size from 353 to $150\text{ }\mu\text{m}$ (0.0139 to 0.0059 in.). Despite the relative coarseness of the abrasive, it produces no visible scratching on workpieces. In drilled holes, for example, it improves the finish from 1.626 to $0.813\text{ }\mu\text{m}$ or better (64 to 32 $\mu\text{in.}$).

Simple shapes, such as open ended cylinders with holes drilled in them, do not require any tooling other than a containment pipe. The abrasive laden carrier (called *media* in the rest of this report) is forced through a hole in the lower tooling plate on the machine (Figure 1). The upper machine tooling plate blocks off the end of the cylinder so the only path for media flow is through the holes in the cylinder. The media passes through holes in the upper tooling plate. Pressure is applied to force the media back through the part and into the lower chamber.

Experimental Results

Small Holes

A previous report¹ indicated that X-base media produced radiusing equivalent to the normal Extrude Hone media but enlarged hole size much less (Figures 2 and 3). Producing an edge radius of $76.2\text{ }\mu\text{m}$ (0.003 in.) in three 0.678 mm (0.027 in.) holes with X-base media enlarged hole size $20.3\text{ }\mu\text{m}$ (0.0008 in.). These results, however, are valid only for the test part shown in Figure 4.

The effects of the amount of abrasive, the media pressure, and the amount of time the media passes through the holes were not analyzed for X-base media in these parts. Figures 5 through 7, however, present the effects of these parameters using the conventional silicone rubber Extrude Hone media. Similar patterns would be expected of X-base media. It is important to note that all these results were from essentially burr-free sharp edged holes obtained by wiping a part on 320 grit abrasive paper to remove heavy drill burrs.

Effects of Burr Size and Volume of Compound Flow

Another brief study was initiated to determine the effects of burr size on final edge radius. The effects on edge radius and change in hole diameter of different volumes of media passing through drilled holes were also evaluated. This study utilized slugs 12.7 mm (0.500 in.) in diameter and 4.76 mm (0.1875 in.) thick with a 3.175 mm (0.125 in.) drilled hole in the center. The samples were drilled at varying feedrates to produce burrs of different sizes. The samples were made from 6061-T6 aluminum (R_B 61), 1018 steel (R_B 93), and 303Se stainless steel (Rc32).

Figure 1. Extrude Honing of Simple Sleeve

Varying amounts of the X-base media were forced through the holes at a gage pressure of 5.516 MPa (800 psi). The X-base powder was mixed one part (by weight) powder to four parts water. Silicon carbide abrasive (70 grit) was mixed into this compound in the ratio of 1 to 1 by weight.

Hole sizes were measured with plug gages to the nearest $2.54\text{ }\mu\text{m}$ (0.0001 in.) before and after the test. Burr heights and thicknesses were measured optically from metallurgical mounts of cross-sectioned samples. Two samples of each material at each feedrate were used for measurements, and two were processed at each of three test conditions. Final edge radii on the holes were measured from metallurgical mounts of cross-sectioned parts. Burrs and radii were measured at each of the four edges seen by cross-sectioning a hole. The results of this study are shown in Figures 8 through 15.

Figure 2. Effect of Volume Flow on Size of 0.6 mm Hole Using 220 SiC Abrasive and 10 MPa Pressure

High, thick burrs slow the edge radiusing action. As seen in Figures 8 and 10, the impact is rather small in 303 stainless steel and aluminum and most noticeable in low carbon steel parts (Figure 12). One would expect, however, that the effect of burr size would be most significant when allowable diameter changes are small. As seen in Figures 9, 11 and 13, a 177.8 μm (0.007 in.) radius was produced on parts only after 38.1 to 114.3 μm (0.0015 to 0.0045 in.) was removed from the diameter. When the allowable stock loss is in the order of 5.08 μm (0.0002 in.), a very large burr would not be removed.

Figure 3. Effect of Volume Flow on Formation of Edge Radii Using 220 SiC Abrasive, a Ratio of 1 to 1 by Weight, and 10 MPa Pressure

Figures 14 and 15 illustrate the relationship between stock loss and edge radius produced when the initial size of the burr is ignored. As seen there, a linear relationship was observed for the stainless steel. The large data scatter for the low carbon steel sample is a result of the obvious relationship between burr size and final edge radius (Figure 12).

Figure 4. Escapement Plate

The results of this study are partially dependent upon the size of burrs used. If it had been possible to produce burrs covering the full range of interest (thin but high burrs, thin but short burrs, and so on) it is probable that burr size would have been more significant on the final edge radius. This is particularly true for situations in which only a 5.08 μ m (0.0002 in.) hole size increase is allowable. The burr sizes used in this study, however, are typical of those found in production situations.

On the majority of miniature parts, a need exists for small (127 μ m or less) edge radii and minimal stock loss. As shown in Figures 8 through 13, hole size change is proportional to the quantity of media passing through the hole. In this particular case, 819 cm³ (50 in.³) was the maximum which could pass through a 3.175 mm diameter hole without exceeding edge radius limits. That is roughly ten times more media than would be allowed to maintain a 5.08 μ m stock loss.

Figure 5. Results of Preliminary Tests on 1.5 mm 302 Stainless Steel, Alloy 6 Brass, and 6061 Aluminum With a 0.678 mm Hole Deburred With 220 SiC Abrasive Using Silicone Rubber as a Carrier

In evaluating edge radiusing and stock losses for different size holes, it is sometimes worthwhile to visualize the length of the stream of media which has to pass through the hole. For example, 98 cm³ (6 in.³) passing through a 0.635 μm (0.025 in.) diameter hole represents a stream 0.635 μm in diameter by 77 meters (3056 in.) long. A volume of 819 cm³ (50 in.³) passing through a 3.175 mm diameter hole results in a stream 103 meters (4074 in.) long.

It is possible to increase the edge radiusing action without increasing stock losses by using a flow restrictor to concentrate action at edges. Figure 16 shows one such example. The key to the success of this operation is that the Extrude Hone media does most of its work at the greatest restriction. In this case the gap (G) is much smaller than the hole diameter so most of the energy is expended in radiusing rather than increasing hole

Figure 6. Effect of Abrasive Ratio on Size of 0.678 mm Hole in 302 Stainless Steel Using Silicone Rubber Carrier, 220 SiC Abrasive, and 10 MPa Pressure

diameter. This technique is reportedly capable of generating radii 127 μm or larger with stock losses of only 0.51 μm . While this may be possible, tooling costs increase noticeably on multi-hole patterns. Without restrictors, it is not possible to achieve large radii without concurrent noticeable size changes. It is possible to produce small radii with large stock losses with appropriate tooling (Figure 17).

High speed motion pictures of the X-base media passing through clear plastic half cylinders indicate that little slug flow occurs. This media acts more like a fluid than a solid, which is one notable difference between it and the silicone base carriers.

Figure 7. Hole Size Increase in a 0.678 mm Hole Caused by Media Pressure Using Silicone Rubber Carrier, 220 SiC Abrasive, a Ratio of 1 to 1 by Weight, and a 98 cm³ Volume Flow on 302 Stainless Steel

Cleaning Media From Holes

Silicone rubber compounds are much easier to remove from parts than the X-base compound, but even the X-base compound comes off readily if the media is not allowed to get hot or dry on the parts. Unlike the silicone rubber compounds, the X-base compound loses all its desirable properties at 54°C. In addition, steam forms within the media cylinders at this temperature. The release of this steam causes a disturbing *bang* when the cylinder head is retracted. When the X-base compound is forced back and forth through a part many times in a short cycle it heats up and becomes as sticky as flypaper. Application of dry ice to the sticky compound will momentarily solve the stickiness problem.

Figure 8. Effect of Burr Size and Volume Flow on Edge Radius for 3.175 mm Hole in 303Se Stainless Steel

Figure 9. Effect of Volume Flow Through Hole on Diameter Increase for 3.175 mm Hole in 303Se Stainless Steel

Figure 10. Effect of Burr Size and Volume Flow Through 3.175 mm Hole on Edge Radius in 6061-T6 Aluminum

Figure 11. Effect of Volume Flow Through 3.175 mm Hole on Diameter Increase in 6061-T6 Aluminum

Figure 12. Effect of Burr Size and Volume Flow on Edge Radius for 3.175 mm Hole in 1018 Steel

Figure 13. Effect of Volume Flow Through 3.175 mm Hole on Hole Size Increase in 1018 Steel

Figure 14. Relationship of Edge Radius to Diameter Change in 303Se Stainless Steel

Figure 15. Relationship of Edge Radius to Diameter Change in 1018 Steel

Figure 16. Flow Restrictor to Increase RADIUSING Action

Normally, ultrasonic cleaning for 5 minutes in 51°C soapy water will remove all traces of the X-base compound and the silicon carbide abrasive particles. If the compound reaches 54°C, a 30 minute cleaning cycle is required.

The typical cleaning cycle consists of removing the part from the machine, blowing the media from the hole with 0.21 MPa (30 psi) nozzles, cleaning ultrasonically, rinsing with water, and air blowing dry. Some scrutiny is required after cleaning to assure that all of the abrasive particles have been removed from the internal features. Since silicon carbide is black and the X-base compound is light blue, it is generally easy to determine if either of these materials remain on surfaces.

In two separate studies, it was found that the cleaning process described left surfaces free of contamination. In the first test, electrical switch contacts were subjected to X-base contamination, cleaned, then baked dry at 93°C for 90 minutes. An evaluation of current loop resistance (CLR) before and after exposure to the media indicated no significant (± 10 percent) change occurred.

Figure 17. Small Radii and Large Stock Losses Can be Produced at the Same Time by Making Tooling Hole Diameters Close to the Final Hole Diameter of the Part

In the second study, the component shown in Figure 18 was subjected to several cleaning steps and cleanliness was measured after each step. With a sequence of rinsing in triethane solvent to remove cutting fluids, Extrude Honing in X-base media, and ultrasonic cleaning in hot soapy water, only 0.001 gram of removable material was found over the entire part. This amounted to a foreign material concentration of 6.7 parts per million, which could have been oil left from fingerprints. When parts were subjected to an additional ultrasonic cleaning in triethane after hot soapy water, less than 1.0 part per million contamination was detected.

These results were obtained by placing the parts in a desiccator for two days to remove surface moisture. To minimize moisture adsorption during weighing, the parts were removed individually and weighed immediately in an analytical balance to the nearest tenth of a milligram. The internal channels of the parts were first washed with 50 ml of distilled water, followed by 50 ml of ethanol and finally 50 ml of chloroform. A portion of each solvent was poured into each opening of the part to ensure complete surface-solvent contact. The parts were allowed to dry in air and then returned to the desiccator for five days. After

this final conditioning, they were reweighed and the concentration of soluble material for each was calculated on the basis of the total part weight. While the parts were in the laboratory, they were handled with white gloves at all times to avoid weight changes from fingerprints.

Makeup and Cleanup

The X-base compound provided by Extrude Hone is a powder; to make a working media, it has to be mixed with water and abrasive. For most applications, one cup dry powder is mixed with 3.5 cups water and 2.5 cups abrasive. This provides a compound-to-media ratio of 1:1 by weight for the gelatinous compound. (Preparation and use of the X-base media is described in more detail in Bendix Process Engineering Specification P1251045.) Because the powder reacts quickly with water, it is necessary to complete all the mixing within 2 minutes. A high speed blender is necessary to prevent lumps in the compound.

Mixing the abrasive into the compound (which is the consistency of bread dough) requires strong hands or a sand muller. The mixture is inserted in the Extrude Hone machine and cycled twice to further homogenize it. The total setup time is approximately 1 hour. At the end of a run, the media is removed from the machine, all moisture and loose abrasive particles are wiped from the machine cylinders which hold the media, and all loose abrasive particles are wiped from the machine. This requires 30 minutes or less. Although the media can be left in the machine overnight, it hardens like concrete if exposed to air for two hours or longer. Loose abrasive particles must be removed if more than one size of particle is used in the machine. Failure to do so invariably results in large particles jammed in small holes.

Production Applications and Limitations

Although this process can deburr and radius washers and other simple shapes, its biggest advantage for deburring is in hard to reach intersections and hole patterns.

The process has little advantage for deburring exposed edges because loose abrasive processes such as vibratory deburring and Harperizing can do small parts much quicker. Extrude Hone deburring parts 50 mm or smaller requires 2 to 5 minutes per part for loading, deburring, unloading and cleaning.

Some typical applications of the process are shown in Figures 18 through 22. In the part shown in Figure 18, media enters the cross hole and exits the two smaller holes. In the component in Figure 19, media passes through the large cross hole and out the slot milled in the threads. In the ceramic stator shown in

Figure 18. Part Having Intersecting Holes

Figure 19. Component Diagram

Figure 20. Stator Switch

Figure 21. Part With Intersecting Holes

Figure 20, media flows into the center hole and out each of the 28 intersecting holes. In the 17-4 PH stainless steel component shown in Figure 21, media passes through the two side holes and out the intersecting vertical hole. The entrance and intersections of these holes are radiused in excellent fashion. The ceramic plate (Figure 22) is another example of the ability to do many holes at one time.

Figure 22. Laser Drilled Ceramic Plate

While these parts are good basic applications for Extrude Hone deburring, several also contain features which limit the usefulness of the process. As an example, there are two limitations shown in Figure 21. At least one counterbore in the two cross holes has a total drawing tolerance of $25.4 \mu\text{m}$ (0.001 in.). Completely removing a heavy burr (101.6 by $127.0 \mu\text{m}$) anywhere in the holes results in more than a $25.4 \mu\text{m}$ diameter increase. If the machined hole sizes cannot be decreased, then the process is limited by burr size. In this particular case, a very thick burr occurs on the bottom of the vertical hole and long flexible fragments occur at the three-dimensional intersection of the vertical and horizontal hole. These must be removed by hand prior to Extrude Hone deburring. (Tall flexible burrs are generally folded over flush with one surface rather than being removed when allowable stock losses are small.) As is often the case after a part is in production, it is difficult to change all the tooling required to produce a given feature, particularly if the repeatability of a subsequent process is not assured.

The controlled stock loss also limits the amount of material flowing over the recesses in the horizontal holes. As a result of the small amount of flow allowed, the fact that many of the recess edges are not in the best flow path, and the fact that the X-base media is more liquid-like than other compounds, the process does not completely remove a normal machining burr in the recesses. In particular it does not remove burrs in the small O-ring grooves.

Although the fixture for this part is designed to prevent flow over the top surface of the part, some material invariably finds its way into the small blind holes in the top. Because the silicon carbide particles and the holes are approximately the same size, it is both difficult and time consuming to remove the particles. Using a finer abrasive particle would minimize this problem, but greatly reduce the radius action at the same time.

The part in Figure 19, while an excellent application for Extrude Hone deburring, is limited by the size of burrs found on it. The large cross hole is produced by the side of an end milling cutter. Because of the dimensions involved, this produces an essentially heavy web (burr) across much of the hole. This burr tapers from 50.8 μm (0.002 in.) thick to the full wall thickness of the cylinder. Even after cleaning out the hole with a drill or end cutting end mill, a relatively heavy burr is left inside the cylinder. Although Extrude Hone does an excellent job of radiusing these edges after the heavy burr is removed, considerable hand deburring is still required.

Slots passing through threaded features are another good application for Extrude Hone if the burrs can be kept short and thin. In most materials, burrs are not short and thin in such situations.

Machined ceramics (Figure 20) have two undesirable features after machining. All edges are typically sharp and fine loose ceramic particles cover the part. The first feature is undesirable if wires pass over the edges, if stress concentrations are a problem, or if in inserting components the edge is likely to crumble and scatter particles throughout the assembly. The second feature is undesirable when close fitting components are used. Without a very thorough cleaning, for example, the fine loose particles will cause a plug gage or component to seize in a hole and, while the gage will slide into the hole easily, it cannot be withdrawn without cracking the part.

Extrude Hone deburring solves these problems easily, particularly since no burr exists on the ceramic. A smooth radius results at the intersection of the holes in such a part. Because of the white color of the ceramic, any foreign material in the hole after cleaning is readily visible. Of all applications of this process, this is one of the most useful.

The stainless steel part shown in Figure 19 is another ideal application for the process--provided the burr is small enough and a radius is allowable at the intersections. If a burr 25.4 by 25.4 μm existed in the intersections, a 101.6 to 152.4 μm radius would be produced with a concurrent diameter stock loss of 2.54 μm using 4900 cm^3 (300 in^3) of 70 grit silicon carbide mixed 1 to 1 at 5 MPa (800 psi) with the wet X-base compound. Deburring under these conditions requires roughly 1 minute per part although 5 to 10 minutes per part would be required for the total cycle through cleaning.

The ceramic plate shown in Figure 22 is another ideal application for the process. In this case, Extrude Hone can be used to clean glazed areas from laser drilled holes as well as to radius the edges. Passing 4900 cm^3 of media through those holes falling within a 50.8 mm diameter circle located at the center of the part increased hole size 101.6 μm when 120 grit media was used at 5 MPa. For the best use without developing large forces on the tooling the entire hole pattern should fall within a 50.8 mm diameter circle. (Upper and lower tooling plates on the machine have a hole in the center. Although different plates can have different hole diameters, it is advantageous not to have to change these plates often. A 50.8 mm diameter hole is typically used on the machine at Bendix.)

Table 1 indicates how media force on the holding fixture varies with the diameter of the tooling hole. As seen in Figure 23, the tooling required for finishing holes in flat plates is very simple.

Figure 24 shows another geometrically ideal part for Extrude Hone deburring. The 0.5 mm holes in this powder metal magnetic core must have a radius to prevent cutting the wires which are wrapped through the holes. Although the part fractured when 70 grit abrasive was used, a 220 grit abrasive would have prevented media lodging and subsequent cracking. It is significant, however, that the media will break down much quicker in a part such as this because more of it is working when it is forced through small holes than through large holes.

Figure 25 illustrates the time required and the repeatability of deburring for one part. The radii produced on this 304 stainless steel component depends upon the location of the edge. Fully exposed edges receive more action than the edge at the bottom of the counterbore. Typically, the standard deviation of edge radii is noticeably larger than the 2.54 to 6.35 μm found on this part. As seen in Table 2, the standard deviation of edge radiusing is 12.7 μm or larger when a hole pattern (as opposed to a single hole) is deburred. The standard deviation of hole size between parts was 3.81 μm for the specimen from which this data was taken

Table 1. Effect of Tooling Hole Diameter on Force on Fixture Using 5 MPa Media Pressure

Hole Diameter		Force	
Millimeters	Inches	Newtons	Pounds
12.7	0.5	698	157
25.4	1.0	2793	628
50.8	2.0	11182	2514
101.6	4.0	44715	10053

(Figure 3). Unfortunately, Extrude Hone repeatability is a function of tooling design, part design, and processing conditions. Holes in the ceramic stator shown in Figure 20 varied $76.2 \mu\text{m}$ after radiusing, which represents a standard deviation of $19.05 \mu\text{m}$ on hole size.

Thermoplastic parts are not good choices for Extrude Hone deburring. The abrasive particles tend to scratch the plastic and, if burrs are large, essentially no deburring occurs. This can be an asset in tool design, since tools made from nylon-like materials appear to last longer than those made from steel.

Extrude Hone deburring can produce some undesirable effects (Figures 26 to 28). Fortunately, causes are easy to identify. In Figure 26, for example, a bright spot surrounding, but offset from, the hole centerline indicates that the clearance hole in the fixture is off location. (A bright spot surrounds any Extrude Hone deburred edge which always makes it possible to determine if a part was subjected to this process.) A gash at one point on the hole periphery is the result of an oversize particle cutting its way over the edge. A smooth excessively radiused portion of a hole can indicate turbulent flow caused by too high a pressure. Asymmetrical holes can occur for the same reason or because tooling prevented uniform flow around the holes.

Impingement indentations on the part indicate that abrasive particles were pressed into the part surface by the tooling (Figure 27). This can be eliminated by wiping particles from the fixture before it is closed. If too much clearance exists between part edges and the fixture cavity, media may flow around edges rather than through holes. The media will always take the path of least resistance. Unequal radii on opposite sides of a part

Figure 23. Tooling Used to
Extrude Hone Holes
in Ceramic Plate

reflect differences in initial burr size, differences in tooling hole size, or noticeably different amounts of flow in the two directions. Part distortion will occur if parts are not adequately supported by the fixture.

Nonuniform edge radiusing can be the result of too large a particle size or turbulent flow (Figure 28).

Figure 24. Powder Metal Magnetic Core

Process Effects

Eight major factors affect deburring aggressiveness:

- Putty type (X-base, silicone rubber, kneaded rubber),
- Putty consistency (viscosity),
- Type of abrasive used,
- Ratio of abrasive to putty,
- Abrasive grain size,
- Media pressure,
- Volume flow, and
- Number of cycle reversals.

LOAD/UNLOAD TIME	1.89 MINUTES PER PART
CYCLE TIME	0.60 MINUTE PER PART
SUBTOTAL	2.49 MINUTES PER PART
BLOW OUT	ON MACHINE CYCLE
CLEAN	0.20 MINUTE PER PART
TOTAL	2.69 MINUTES PER PART
TOTAL VOLUME 966 cm ³ (59 IN. ³)

EDGE NUMBER	TYPICAL RADIUS (μ m)	TYPICAL VARIATION (μ m)	TYPICAL SIZE CHANGE (μ m)
1	58.0	12.7	
2	17.8	5.1	10.2
3	55.9	5.1	

Figure 25. Extrude Hone Data on Stainless Steel Hub

Table 2. Repeatability of Extrude Hone Deburring

Variable	Stainless Steel		Brass	
	Silicone Rubber Media	X-Base Media	Silicone Rubber Media	X-Base Media
Typical Radius				
μm	71.7	63.5	76.2	88.9
Inch	0.0028	0.0025	0.0030	0.0035
Radius Variation Within Part ($\pm 2\sigma$)				
μm	± 35.6	± 35.6	± 7.6	± 94.0
Inch	± 0.0014	± 0.0014	± 0.0003	± 0.0037
Radius Variation Within Group of Parts ($\pm 2\sigma$)				
μm	± 50.8	± 25.4	Data Not Available	± 30.5
Inch	± 0.0020	± 0.0010		± 0.0012
Typical Hole Change				
μm	58.4	10.2	91.4	10.2
Inch	0.0023	0.0004	0.0036	0.0004
Hole Size Variation Within Part ($\pm 2\sigma$)				
μm	± 7.6	± 1.3	± 12.7	± 1.3
Inch	± 0.0003	± 0.00005	± 0.0005	± 0.00005
Hole Size Variation Within Group of Parts ($\pm 2\sigma$)				
μm	± 35.6	± 7.6	Data Not Available	± 7.6
Inch	± 0.0014	± 0.0003		± 0.0003

These results reflect a wide variety of test conditions. The repeatability in a production situation could be better than indicated here. A 220 grit SiC abrasive was used in this study; the abrasive to carrier ratio was 1 to 1 for both media. Typical total flow was 93 cm³ and the pressure was 11 MPa (1600 psi).

The number of cycle reversals appears to be as significant as volume flow in forming radii. For example, if 490 cm³ (30 in.³) of media is placed in the machine instead of 980 cm³ (60 in.³), twice as much radiusing will occur for a given volume of flow.

Figure 26. Off Center Bright Spots, Gash Around Edges, Smooth Flow Gouge, and Asymmetrical Holes in Extrude Hone Deburring

IMPINGEMENT MARKS

UNEQUAL RADII

PART DISTORTION

LEAKING AROUND PART EDGES

Figure 27. Impingement Marks, Leaking Around Part Edges, Unequal Radii, and Part Distortion in Extrude Hone Deburring

INCOMPLETE RADIUSING OF HOLE CAUSED
BY TURBULENCE. ABRASIVE COMPOUND
WAS FLOWING TOO FAST

NONUNIFORM RADIUSING CAUSED BY
PARTICLE THAT WAS TOO LARGE

Figure 28. Incomplete and Nonuniform Radiusing in
Extrude Hone Deburring

This is consistent with the thixotropic property of silicone putties. It takes less energy to keep the media moving than it takes to start it. As the media first approaches a restriction it acts as a slug of material and exerts a high force on the restriction. As uniform flow begins, the force on the restriction decreases and so does the rate of edge radiusing. At the start of each up or down cycle, the media acts as a slug of material.

On some long holes, waviness or ripples can be seen in the surface after Extrude Hone deburring. One cause of these ripples in long holes is lumps in the media. Unless a high speed blender is used to mix the X-base powder with water, a number of large lumps will form. High speed movies taken through plastic fixtures indicate that the X-base media tends to surge through the holes. This surging also contributes to some of the waviness.

The volume of media forced up on the first stroke is larger than the volume forced down by 164 cm^3 (10 in.³) plus the open volume in the fixture. This material is captured in a small cavity at the bottom of the top cylinder.

The largest abrasive size that can be forced through the hole and provide deburring or cutting is roughly one-third the size of the hole it is to go through. The effective limit, however, is one-fifth the hole size. At one-third the hole size, media begins packing in the holes. At one-fifth the hole size, the media cuts the edges it passes over but it does not cut uniformly around the diameter. As a result, the hole entrance appears more like a polygon than a circle (Figure 28). At one-twelfth the abrasive action is uniform.

The fluidity of the media can be monitored by passing it through a known hole size. Typically, a new batch of media will pass through a 12.7 mm diameter hole 12.7 mm long at a rate of 49 to $327 \text{ mm}^3/\text{s}$ (3 to 20 in.³/s). In a complex part, the flow slows to 3 to $27 \text{ cm}^3/\text{s}$ (0.2 to 1.7 in.³/s).

Figures 29 and 30 illustrate the effect of abrasive grain size and pressure on hole size.

Tooling Effects

Simple tool designs increase media life and improve radiusing in addition to minimizing tool costs. Small diameter passages accentuate the breakdown of media. Large passages and reasonable clearances are desirable tool properties. If holes are too small or too long, the media will not flow through the holes. To some extent the radius produced on the part is influenced by the tooling design. Tooling Hole 1 in Figure 31 will result in a larger part radius than Hole 2, apparently because of drag.

Figure 29. Effect of Abrasive Grain Size on Hole Size

Figure 30. Effect of Media Pressure on Hole Size Using X-Base Media

Figure 31. Small Diameter Holes in Tooling Result in Increased Wasted Work

Deburring action is also a function of tooling hole size. The larger a tooling hole, the greater the deburring action. For 1 mm (0.040 in.) diameter holes, tooling holes should be 0.381 mm (0.015 in.) larger. On holes 6.35 mm (0.25 in.) in diameter, tooling holes should be larger by 3.18 mm.

Analysis of Published Results

Although several articles²⁻⁸ of a general nature have been published on the Extrude Hone process, none have presented any information on X-base media. Four references, however, provide data on the capabilities of other Extrude Hone or other competitive materials.

Heglin^{9,10} presents a series of nomograms for predicting hole size change as a function of workpiece thickness, initial hole diameter, volume through hole, pressure, and media temperature. His study was based on 0.381 to 1.575 mm (0.015 to 0.062 in.) diameter laser drilled and EDM holes in turbine blades. His study involved Extrude Hone media as well as media from Dynetics Corporation, Woburn, Massachusetts. The repeatability of hole change was controlled within 30 percent of the change in hole diameter; thus, the repeatability when 101.6 μ m material was removed from the hole was 30.5 μ m. It was also observed that the media would not clean holes smaller than 0.381 mm diameter with hole lengths exceeding 1.27 mm.

Table 3. Extrude Hone Effects on Surface Finish¹¹

Original Finish (μm)($\mu\text{in.}$)	Final Finish (μm)($\mu\text{in.}$)	Stock Removal Per Wall (μm)(in.)	Processing Time (Minutes)
2.5 (100)	0.4 to 0.5 (16 to 20)	25.4 to 50.8 (0.001 to 0.002)	1 to 3
1.5 (60)	0.3 to 0.4 (12 to 16)	12.7 to 50.8 (0.0005 to 0.002)	0.5 to 2
1.0 (40)	0.2 to 0.4 (8 to 12)	12.7 to 50.8 (0.0005 to 0.002)	1 to 2
0.8 (30)	0.1 to 0.2 (4 to 8)	12.7 to 50.8 (0.0005 to 0.002)	1 to 3

In a recent advertisement,¹¹ Extrude Hone has presented the data in Table 3 indicating the surface finish which can be obtained from the Extrude Hone process. Many of the current machines being sold are used for polishing rather than deburring.

Perry¹² presents data on the flow characteristics of Dynetics Corporation media and the effect of pressure, type, and size of abrasive grain on stock loss and edge radius. This data was based on silicone rubber compounds.

ACCOMPLISHMENTS

The effects on hole size and edge radius of Extrude Hone deburring using X-base media have been determined. The effect of burr size on the process has been noted, and typical production limitations of the process have been described. Guidelines for selecting Extrude Hone deburring conditions have been prepared (Appendix).

FUTURE WORK

No future studies are planned on Extrude Hone deburring, although additional data on stock loss and effects of burr size for different hole sizes would be useful.

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²Charles R. Rhoades, "Explanation of the Nature and Application of the Extrude Hone Process." *SME Paper MR 70-517*, 1970.

³"New Process For Those Problem Deburring Jobs," *Production*, November 1970.

⁴"Extursion Process Deburrs Difficult Jobs," *Automation*, September 1970, pp 14-15.

⁵Lawrence Rhoades, "An Explanation of the Extrude Hone Process and the Tooling Concepts Employed in Using It." *SME Paper TE-72-818*, 1972.

⁶H. Hauri, "Deburring," *Werkstatt Y Bietriub*, 1972.

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⁸Lawrence J. Rhoades, and David E. Siewert, "Extrude Hone Deburring: Theory and Application of Abrasive Finishing." *SME Paper MR 75-842*, 1975.

⁹L. M. Heglin, *Laser Drilling*, General Electric Company (Aircraft Engine Group) Report IR-739-3 (v), July 1974.

¹⁰L. M. Heglin, *Laser Drilling*, General Electric Company (Aircraft Engine Group) Report A FML-TR-75-44, April 1975.

¹¹*Precision Metal*, July 1973, p 68.

¹²Winfield B. Perry, "Properties and Capabilities of Low Pressure Abrasive Flow Mediae," *SME Paper MR 75-831*, 1975.

Appendix

PROCESSING DETAILS FOR EXTRUDE HONE DEBURRING

- 1 Selecting Extrude Hone Parameters.
 - 1.1 Abrasive carrier. The only abrasive carrier available at Bendix Kansas City is Extrude Hone's X-base powder. This will normally be mixed with 4 parts water to 1 part powder (Table A-1 and Bendix Process Engineering Specification 1251045). Higher water-to-powder ratios make a less viscous carrier.
 - 1.2 Abrasive size. Either 70 or 120 grit abrasive will be used for precision parts. For best results use an abrasive particle size which is 10 percent of the size of the smallest opening. Table A-2 presents average particle sizes of abrasive grit.
 - 1.3 Abrasive ratio. Normally a ratio of 1 part by weight abrasive to 1 part by weight mixed carrier will be used. The mixture becomes more aggressive as more abrasive is added. Abrasive can be added up to a ratio of 4:1.
 - 1.4 Pressure. The pressure will normally be set at 5.515 MPa (800 psi). Higher pressures do more work but quickly break down the abrasive carrier. The maximum pressure available is 9.375 MPa (1500 psi). By using special tool designs (and the same approaches as in conventional hydraulics), it is possible to increase pressures. The pressure on upper and lower cylinders can be individually controlled.
 - 1.5 Volume. A typical volume flow passing through the part (or over an edge) should be such that a column of media 254 to 762 meters (1000 to 3000 in.) long passes over the feature to be deburred. In the case of holes, this can be calculated from the following equation.

$$\text{Volume} = n\pi r^2 L,$$

where:

n = Number of holes to be deburred,
r = Radius of hole(s), and
L = Column length of media

Table A-3 presents some typical values. Volume flow is based on the amount of media flowing in one direction. An equal amount (less cavity in upper tooling plate and cavities in part and in fixture) will flow in the opposite direction.

Table A-1. Mixing Ratios for Extrude Hone X-Base Media

Weight Ratios				Volume Ratios			
Abrasive to- Media Ratio	X Media (Grams)	Water (Grams)	Abrasive (Grams)	X Media (cm ³)	Water (cm ³)	Amount of Abrasive (cm ³)	
						SiC	Al ₂ O ₃
4:1 Water-to-Media Ratio							
0.5:1	200	800	500	236.6	828.1	295.8	236.6
1:1	200	800	1000	236.6	828.1	591.5	473.2
2:1	200	800	2000	236.6	828.1	1183.0	946.4
3:1	200	800	3000	236.6	828.1	1774.5	1419.6
4:1	200	800	4000	236.6	828.1	2366.0	1892.8
6:1 Water-to-Media Ratio							
0.5:1	200	1200	700	236.6	709.8	414.0	315.4
1:1	200	1200	1400	236.6	709.8	828.1	631.7
2:1	200	1200	2800	236.6	709.8	1656.2	1261.1
3:1	200	1200	4200	236.6	709.8	2484.3	1892.8
4:1	200	1200	5600	236.6	709.8	3312.4	2524.5

Table A-2. Average Particle Size of
Abrasive Grain

Alundum and Crystolon Grit Size	Average Particle Size	
	Micrometers	Inches
4	6848	0.2577
6	5630	0.2117
8	4620	0.1817
10	3460	0.1366
12	2550	0.1003
14	2100	0.0830
16	1660	0.0655
20	1340	0.1528
24	1035	0.0408
30	930	0.0365
36	710	0.0280
46	508	0.0200
54	430	0.0170
60	406	0.0160
70	328	0.0131
80	266	0.0105
90	216	0.0085
100	173	0.0068
120	142	0.0056
150	122	0.0048
180	86	0.0034
220	66	0.0026
240	63	0.00248
280	44	0.00175
320	32	0.00128

Table A-2 Continued. Average Particle Size of Abrasive Grain

Alundum and Crystolon Grit Size	Average Particle Size	
	Micrometers	Inches
400	23	0.00090
500	16	0.00065
600	8	0.00033
900	6	0.00024

Table A-3. Volume Flow Through Various Hole Sizes

Hole Diameter		Volume Flow Producing Column Length of Media of 'L' in a Single Hole (cm ³)(in. ³)	
		L = 25.4 m (1000 in.)	L = 76.2 m (3000 in.)
mm	Inch		
0.635	0.025	8.2 (0.5)	24.6 (1.5)
1.575	0.062	49.0 (3.0)	147.0 (9.0)
3.175	0.125	201.5 (12.3)	604.4 (36.9)
6.350	0.250	804.3 (49.1)	2412.8 (147.3)

Table A-4 provides some starting estimates on the effect of burr size on stock loss produced in removing the burr. As indicated in the main body of this report, 819 m³ (50 in.³) removed a 127 by 127 μ m (0.005 by 0.005 in.) burr in stainless steel while increasing hole size by 127 μ m. For all practical purposes, it can be assumed that burr removal is directly proportional to volume flow. Thus a 25.4 by 25.4 μ m burr should require one-fifth the volume flow that a 127 by 127 μ m burr requires.

Table A-4. Estimated Ratio of Burr Size to Stock Loss in Stainless Steel

Tooling Approach	Hole Pattern	Burr Size to Stock Loss Ratio*	Estimated Size Repeatability**
Conventional	Single Hole	1:1	0.3
	Multi-Hole	1:1	0.5
With Restrictor	Single Hole	3:1	0.3
	Multi-Hole	3:1	0.5

*Assuming burr is triangular in cross-section with height equal to thickness

**Percentage of stock loss

- 1.6 Volume per cycle. A typical volume per stroke used on small parts is 490 cm³ (30 in.³). Reducing the volume of abrasive compound per stroke from 980 to 490 cm³ appears to double the amount of radiusing on the part. This variable is controlled by putting only the volume desired into the bottom cylinder. It can be monitored by the display of cubic centimeters forced through the part on the initial stroke.
- 1.7 Effect of workpiece material. Soft materials such as brass are eroded much faster than hard materials.
- 1.8 Problems. Table A-5 lists some common problems and solutions in Extrude Hone deburring.
- 1.9 Preparatory work. Burrs higher than 127 μ m should be removed by some other technique on close tolerance parts. While this necessitates two deburring techniques, the Extrude Hone process provides a smooth blend not obtained by many other processes.
- 1.10 Improving the Extrude Hone operation. Figure A-1 illustrates the process changes that should be made to improve the process. Each item is listed in the sequence in which it should be tried.

Table A-5. Problems and Corrections in Extrude Hone Deburring

Observed Effect	Cause	Correction
Offcenter Bright Spots Around Hole	Offcenter Tooling Holes	Make New Fixture or Rebore Tooling Holes
Gash Around Edge	Large Media Contamin- ating Process	Screen Media or Use Fresh Media
Smooth Flow Gouge	Turbulent Flow or Incorrect Tooling Path	Slow Media Flow or Revise Tooling
Nonsymmetrical Flow	Turbulent Flow or Incorrect Tooling Path	Slow Media Flow or Revise Tooling
Impingement Marks	Abrasive Media Not Cleaned From Fixture	Blow Fixture Clean
Part Distortion	Pressure Causes Too Large a Force on Part, or Media Has Worked Below Plastic Pad	Provide More Support in Fixture; Repour Plastic in Fixture
Unequal Radii	<ul style="list-style-type: none"> • Unequal Amounts of Flow • More Restriction at One Edge Than at Other • Larger Initial Burr at One Surface Than at Other 	<ul style="list-style-type: none"> • Utilize Different Cylinder Pressures or Amounts of Flow • Enlarge Tooling Paths • Produce Equal Burr Sizes
Bright Spots or Wear at Unexpected Areas	Poor Seal Around Part; Media Taking Easiest Path	Check and Revise Tooling if Worn; Check Part For Initial Flat- ness and Roundness
No Deburring; Machine Does Not Complete Cycle	Packing of Media	Increase Viscosity or Pressure
Variation in Hole Sizes on Same Part	<ul style="list-style-type: none"> • Packing of Media in Part or Fixture Hole • Abrasive Particle Shields Hole 	Adjust Media Flow
Media Sticks to Workpiece	Carrier Compound Too Hot	Let Media Cool

Figure A-1. Guidelines for Improving Extrude Hone Deburring

2 Tooling

- 2.1 Concepts. For deburring or radiusing, the tooling must be designed to change the direction or restrict media flow. To assure adequate flow, the area open to flow in the fixture must be greater than the area in the part through which the media must pass. A 0.64 mm diameter hole, for example, may require 2.54 mm diameter tooling holes.

When the piece part has cavities of two different sizes, a restriction must be placed in the fixture to equalize the flow for each unit of area. For example, to deburr a 3.18 mm hole and a 9.5 mm hole in the same part, a pin might be built into the tool to restrict flow in the 9.5 mm diameter hole. The actual pin diameter depends upon tool design and the media used.

- 2.2 Basic design. Tooling will typically consist of upper and lower fixture plates and a center section. The fixture plates should be designed to bolt to the tooling plates on the machine. Fixture plates should utilize non-symmetric features to assure fool-proof operation. If possible, plates should fit together in a nested design rather than being pinned. All piece part locations should be done with only one fixture plate (typically bottom plate or center plate). The other plates then serve only as seals and as media directors.
- 2.3 Locating surfaces. To prevent surface damage, locating features may be covered with a hard plastic such as Teflon or Nylatron (a urethane). This material can be case into fixture cavities. Some caution is required during machining of the plastic because of the soft nature of the material. If urethane pads are used to protect parts, they must be bonded to the tool because deburring media will work beneath pads not bonded and will result in part damage. A typical urethane used in Hysol Corporation's oven cured RU 2028/H3763 with Hysol's P-10STD primer used prior to bonding (*Hysol Bulletin AL2-501A*).
- 2.4 Design details. Tooling must be designed to minimize part deflection. This requires minimization of workpiece area exposed to the 5.5 to 10.3 MPa (800 to 1500 psi) media pressure. Typically, the part should be nested such that it cannot move more than 127 μm in any direction. The tooling should not clamp against the part. Tooling machined out of nylon-like materials exhibit long life and minimize sealing and impingement problems.

- 2.5 Development tools. Because of the number of process variables involved, development tooling should be utilized to prove-in a process whenever possible.
- 2.6 Forces. The Extrude Hone machine is designed to withstand 10.3 MPa distributed across a 152 mm diameter. The force on the tooling caused by the media pressure will depend upon the size of the opening in the tooling plate. Plates are available with 6.35, 12.7, 25.4, and 50.8 mm diameter holes.
- 2.7 Media life. The X-base media life is a function of how hard it is worked. Under normal circumstances, it can be used for at least eight hours of deburring. The key to longer life is to prevent the media from getting warmer than 49 to 54°C. The use of larger abrasive, minimizing burr size or otherwise minimizing the amount of cycles the media must undergo to remove burrs, is required to keep media cool.

The shelf life of mixed media is roughly two months in tightly sealed bags. Exposure to air will harden media in only a few hours.

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