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Deburring: Technical Capabilities and Cost-Effective Approaches Lessons 3 and 4

By L. K. Gillespie

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This ten lesson text on deburring is designed to provide engineers and production supervisors with an overall understanding of deburring economics and current capabilities. The material included describes economics, side effects, process selection techniques, product design influences, standards, plantwide approaches, burr formation, and prevention. Deburring methods described include barrel, centrifugal barrel, vibratory, spindle, manual, electrochemical, electropolish, brush, abrasive jet, abrasive flow, water jet, thermal energy, and mechanized mechanical. Lessons 3 and 4 describe product design influences and burr prevention and minimization respectively.

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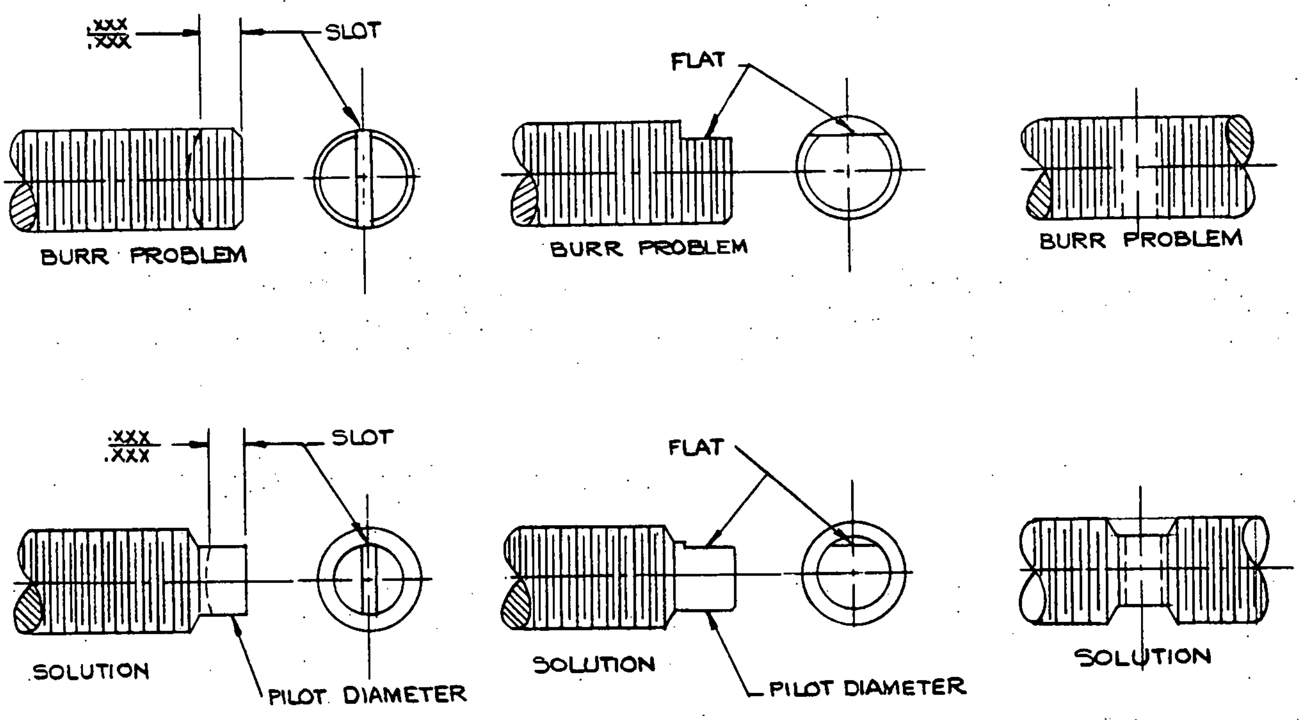
Deburring: Technical Capabilities and Cost-Effective Approaches

by LaRoux K. Gillespie

Lesson 3
Product Design Influences



LESSON 3

PRODUCT DESIGN INFLUENCES

Many deburring problems can be minimized by a thorough analysis of actual product design requirements. The factors which influence burrs and deburring include:

- Part geometry;
- Workpiece material properties;
- Workpiece tolerances; and
- Edge standards.

Designing to Eliminate Deburring

Some components and assemblies can obviously operate adequately without deburring. The mechanisms in many children's moving toys for example need not be deburred. Sheet metal edges are often more aesthetic and trouble free if a rolled edge is produced. In this case deburring is not required on the hidden edge. Both of these examples are a direct result of design requirements. In the first case the designer somehow had to specify that edges could have burrs. In the second case the designer used the geometry of the part to reduce deburring. The majority of assemblies may not lend themselves to such obvious design changes. The point is; however, that if deburring can be eliminated from even one part in an assembly there is a consequent cost savings. Two common examples in which burr removal is not required are shown in Figures 1 and 2. Pins which are pressed into a hole often do not have to be entirely burr free. In Figure 2b the part was machined so that the burr was thrown into the shoulder relief. Since the burr does not interfere with part function and cannot escape from the relief, deburring is not required.

Edge Angle Effects

The shape of piece parts and the location of burrs on these parts play a major role in burr removal efforts. One of the most obvious examples occurs when a cutting tool passes over an edge on its way out of a part (Figure 3). The size of the rollover burr produced is a function of included angle in the edge (Figure 4). When the cutter passes over an edge having an angle much larger than 90° little or no burr forms on the edge. Conversely when the edge angle is small (Figure 4) a large burr forms because there is no support for the metal being cut. As seen in Figure 4 no noticeable burr is produced when edge angles exceed 150°. There is essentially no space left for material to bend into with

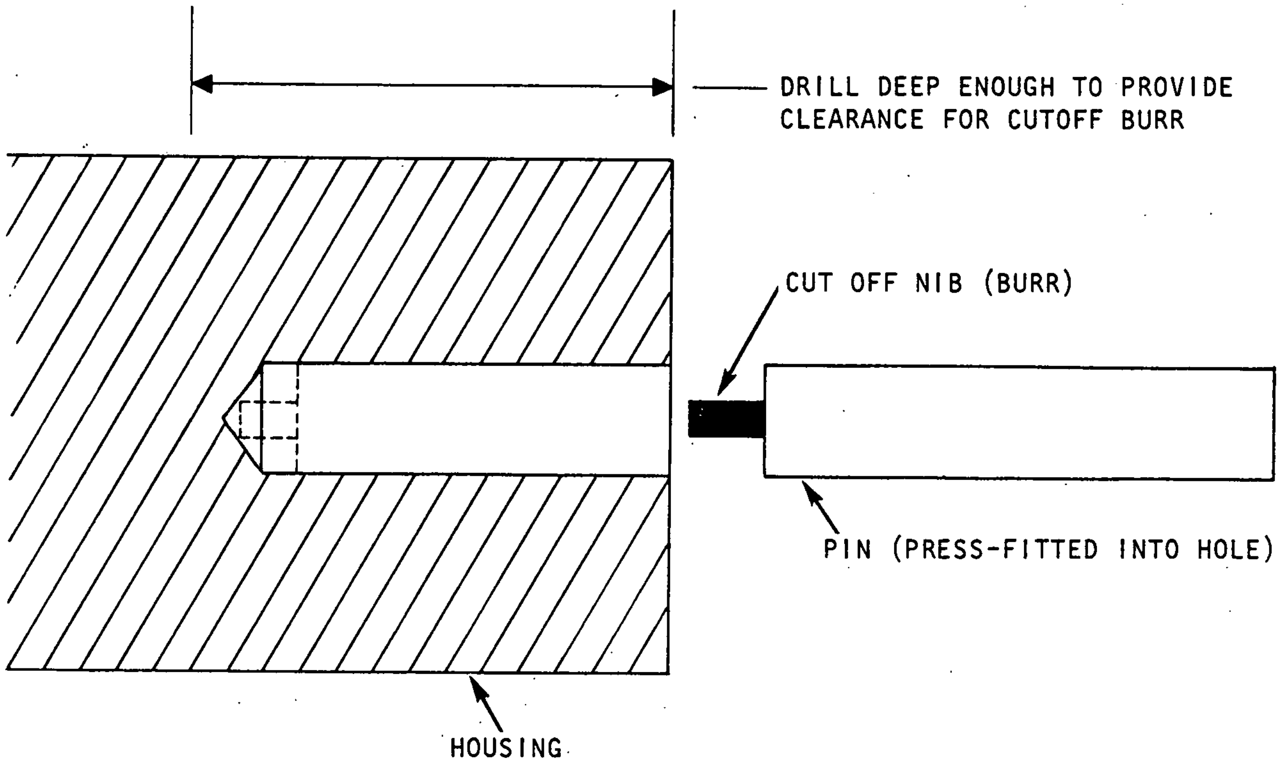


Figure 1. Take Advantage of Part Design to Minimize Deburring

these large angles. While the data presented in Figure 4 was taken from low carbon steel in an unhardened condition the basic phenomenon can be observed in all materials.

Figure 5 illustrates a practical example of how this phenomenon can be used in production. The upper left hand view illustrates the heavy burr (solid black) which occurred when a casting was faced with a mill to provide a locating surface. Because of the small angle ν and a 90° edge perpendicular to plane AA', a heavy web of material extended across the inner diameter of the part after milling. This could only be removed by hand or by adding a special trimming operation. While a trimming press could remove most of the burr it left an objectionable stub projecting into the center hole. By redesigning the casting so the cutter exited over a large angle ν a much smaller burr was produced which could be removed by abrasive jet deburring. Redesigning the casting so that only a small land had to be machined eliminated the heavy web-like burr produced by the face mill. The success of this approach is the result of three factors:

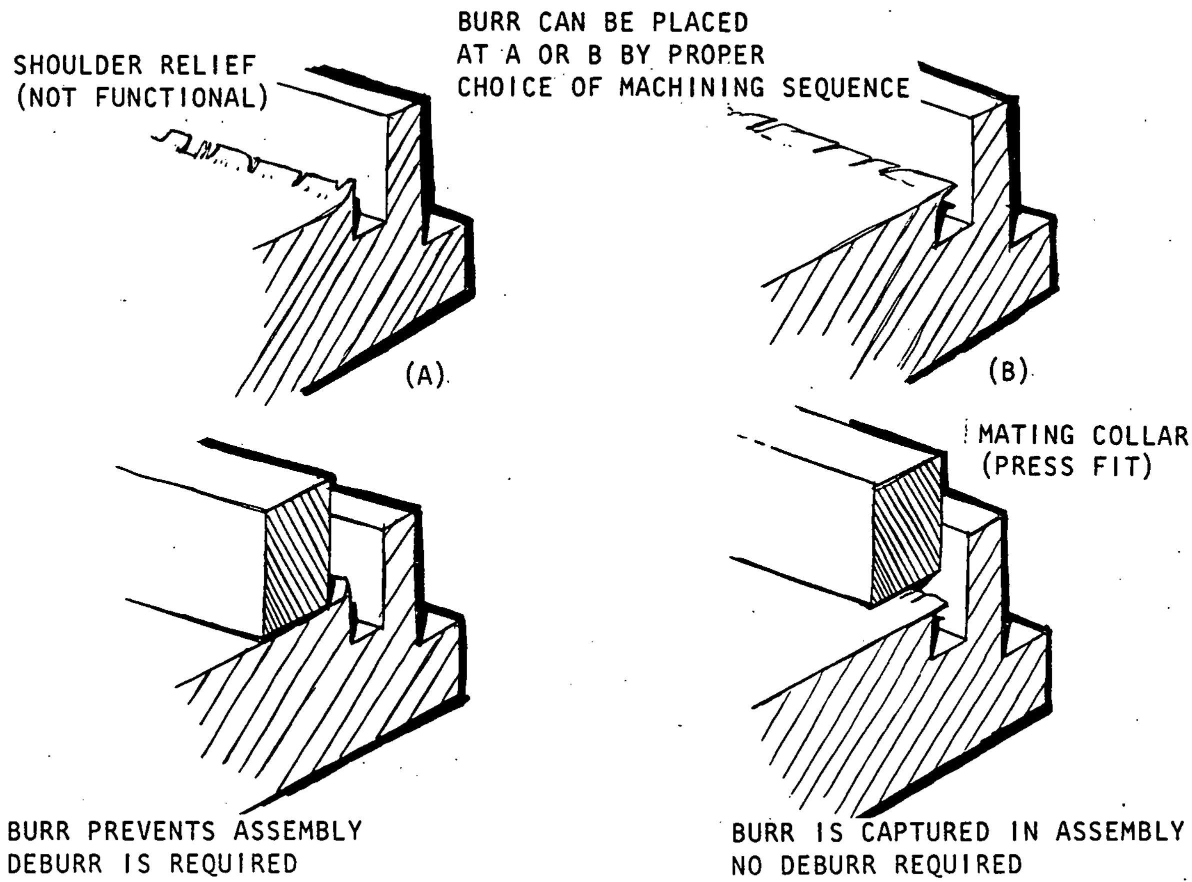
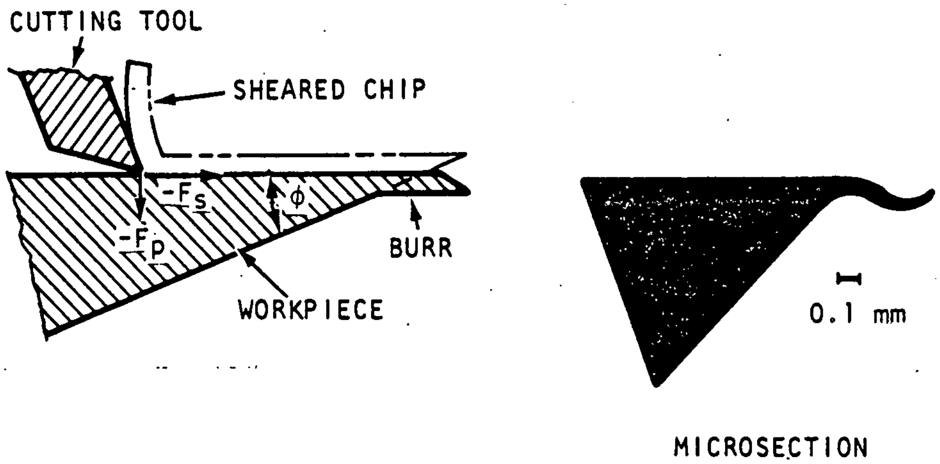


Figure 2. Impact of Burr Location

- By eliminating much of the material that went into the burr, the burr was shorter;
- By changing angles at which the cutter exited from the cut, a smaller burr was produced; and
- By designing draft into the boss, a resultant larger, included edge angle minimized the burr size.

As an example of this third principle, consider what happens when a cutter exits over a 90° edge (Figure 6). A burr is always produced on the exit side. Its size is a function of cutting forces and material properties. The thickness of this burr can be calculated from formulas in Chapter 2. Consider now the case where ϕ is almost 180° (Figure 7). If it were 180° no burr could be produced because it would be a continuous surface. If it were 1 minute less than 180° it would also essentially be a continuous surface. This philosophy of inching away from 180° can be continued

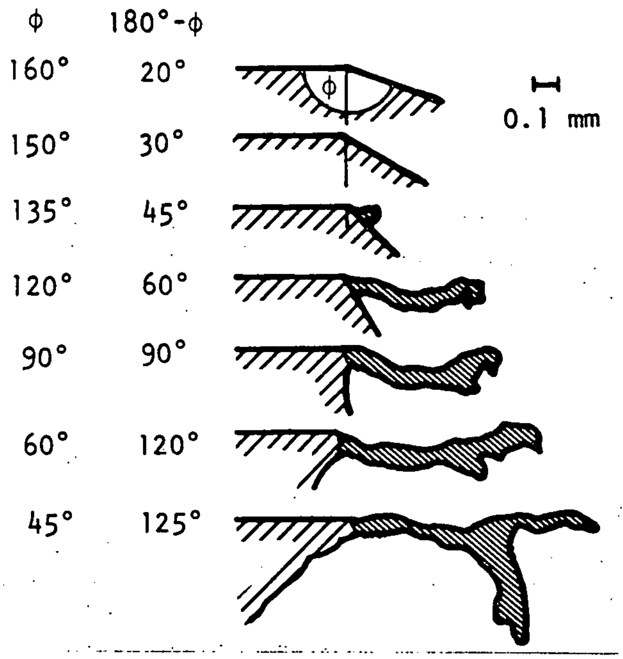


F_s = CUTTING FORCE

F_p = COMPONENT OF RESULTANT CUTTING FORCE

BURR FORMATION WITH EDGE ANGLE ϕ << 90°

Figure 3. Burr Formation at End of Cut



EFFECT OF WORKPIECE EDGE ANGLE ON SIZE OF ROLLOVER BURR

Figure 4. Effect of Workpiece Edge Angle on Size of Roll-Over Burr

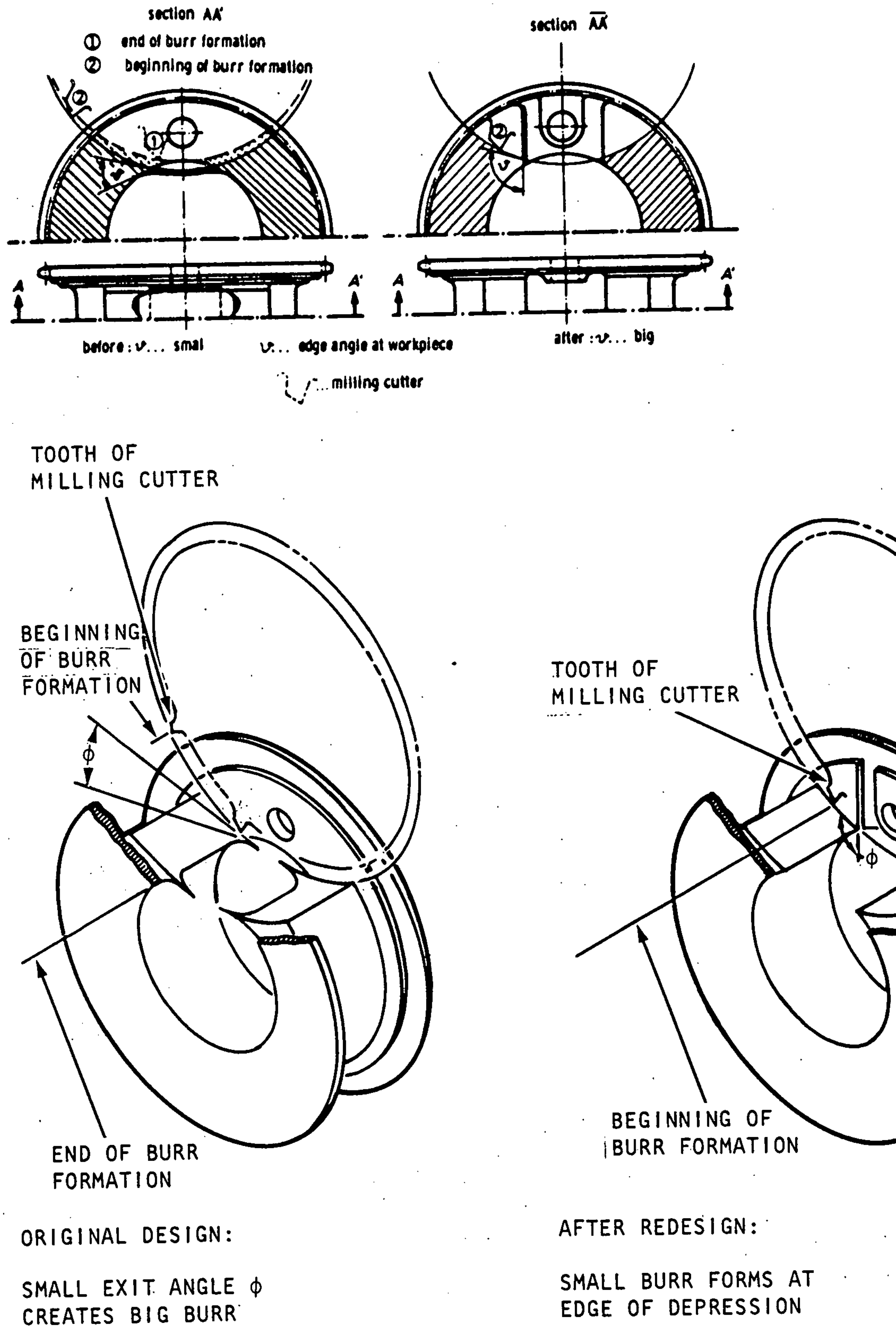


Figure 5. Casting Before and After Redesigning for Burr Minimization

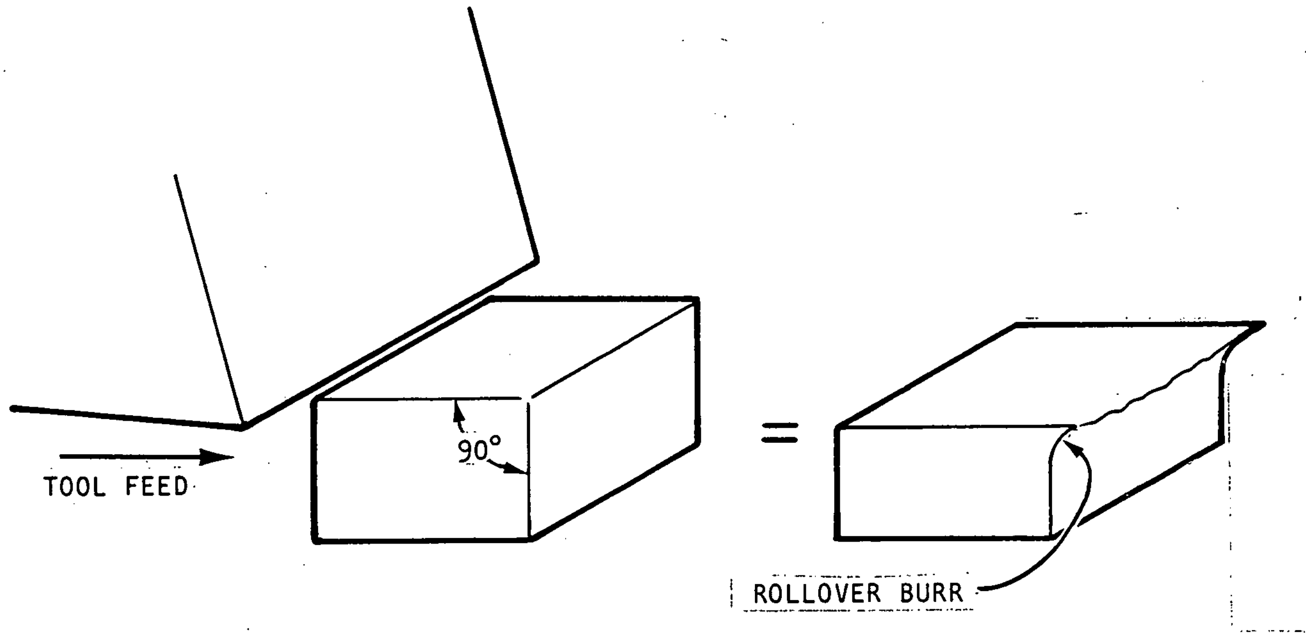


Figure 6. Burr Formed at 90° Edge

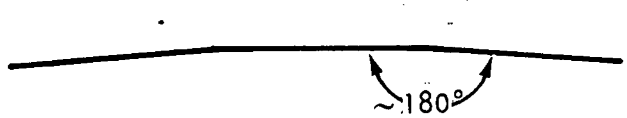


Figure 7. Edge Angle of Nearly 180° Approximates a Continuous Surface

until it is obvious that some definite departure from a continuous surface exists. As just indicated, no burr will occur when the edge angle exceeds 150°.

From a practical standpoint 90° edges are preferred on most machined components because they are easier to design, inspect, and machine. On cast parts; however, an angle larger than 90° is required in order to remove parts from the mold. Draft is required in forgings to increase tool life as well as for part removal. The draft angle generally used for castings is in the order of 1 to 5°. If the draft were larger, the included edge angle would be 150° and no burr would form when these features were machined.

If such a large angle is not possible in the machined part because of geometry, the possibility of a short land with this angle should be pursued (Figure 8). Note that a properly selected radius on the casting is as effective as a constant angle (Figure 9).

Since roll-over burrs occur in all machining operations, it is possible to eliminate the burrs from drilling, turning, grinding, and other processes as well as from milling operations. Figure 10 illustrates how cored holes should be designed if they must be drilled or reamed.

The extra advantage to large edge angles is the elimination of the large stress concentrations which occur at 90° edges. Over 2 billion lineal inches of glass are chamfered each year for just this reason.

A similar burr size effect can be seen when one examines the angle at which the cutter exits from a surface. In Figure 11 for example, the angle ϕ dramatically effects burr size. In this case burr heights will vary from no burr to 1/8 inch (0 to 3.2 mm). While manufacturing controls this aspect more than design engineering, there are instances where the designer and the manufacturing engineer working together can take advantage of this geometry effect.

Figure 12 illustrates another significant aspect of edge angles. The amount of radius that can be produced economically by vibratory finishing after removing the burrs is a function of the angles between intersecting surfaces. Large radii can be produced relatively quickly when the included angle is large. Finishing times are 20 times longer when the included angle is 30° than when it is 120° (Figure 13). However, precision edge radius tolerances are harder to maintain when large angles are present. When a component has features involving several different edge angles, edge radii will vary significantly (Figure 14 and Table 1). Designers must recognize this when assigning tolerances to edge radii if they want to eliminate the extra costs required to produce equal radii.

Cutouts and Undercuts

Edge angles are not the only geometry factor which contribute to high deburring costs. Undercuts of the type shown in Figure 15 should be avoided because it is difficult to reach burrs under ledges and in corners. If an undercut occurs on only one side of the part, the manufacturing engineer can prevent the occurrence of heavy burrs by assuring that the cutter enters, rather than exits, the workpiece at these edges.

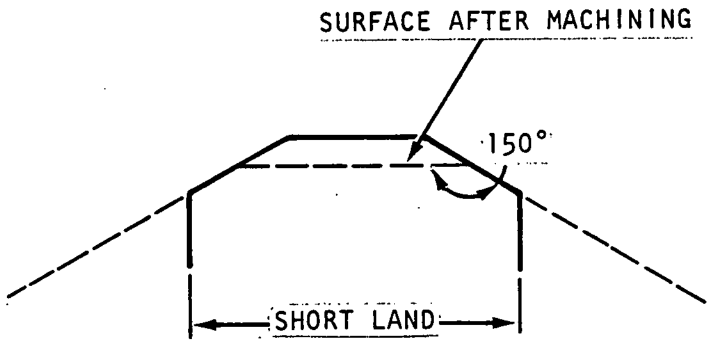


Figure 8. Use Short Land Having 150° Angle, When Full Length of 150° is Not Feasible

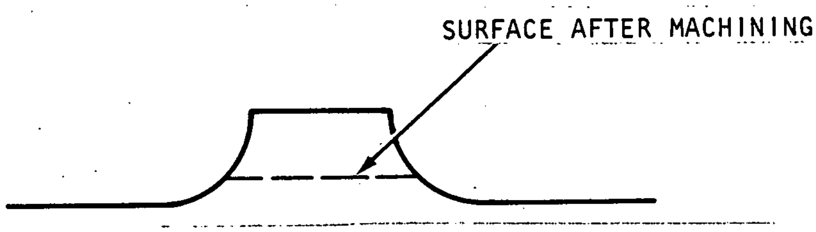


Figure 9. Fillet Radius Can Result in Large Edge Angle

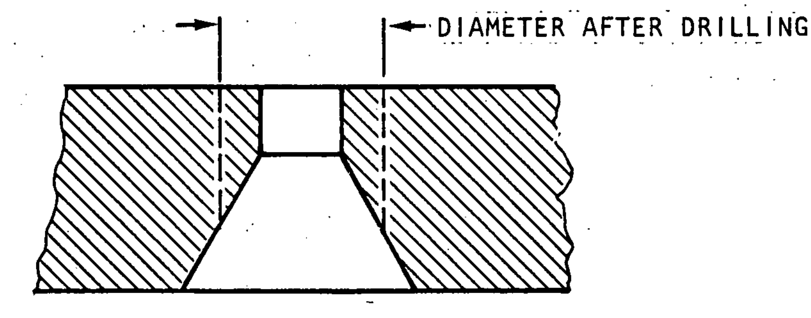


Figure 10. Relief of Cored Holes Will Help Reduce Burr Size When Hole is Finished-Machined

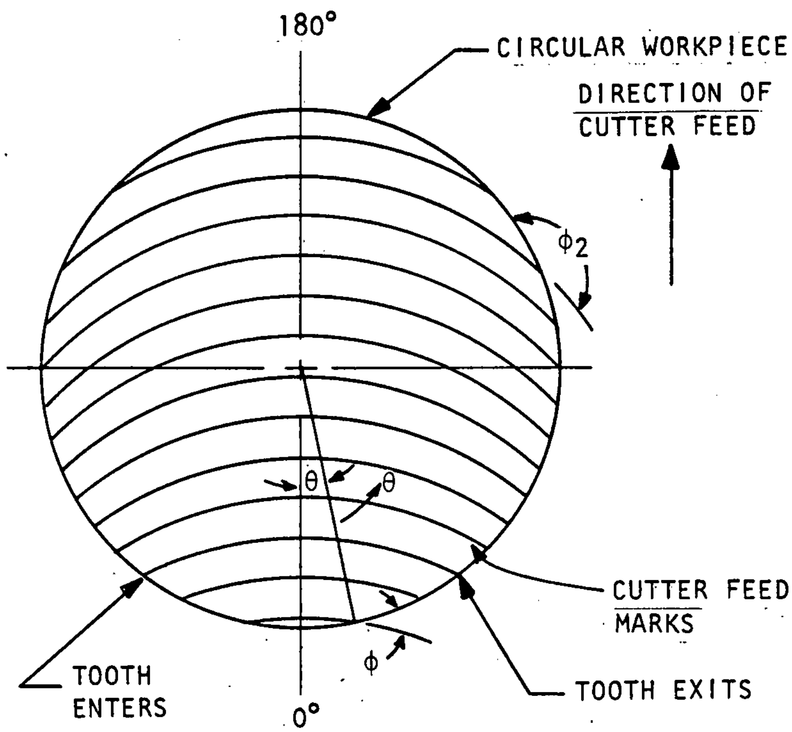


Figure 11. Angles Observed When Face Milling Cylinder Face

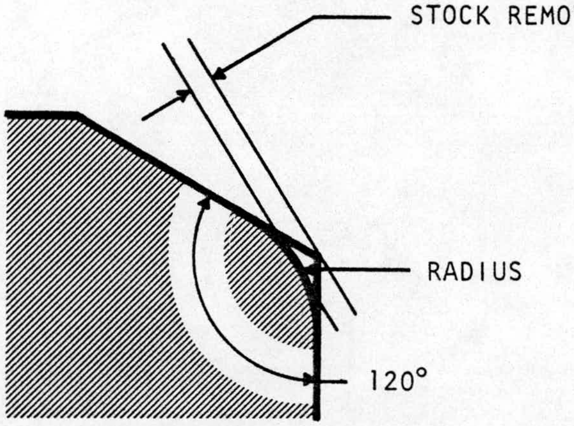
Threading typically swells material at the entrance and exit of the hole. When the shoulders must fit flush in the assembly, specifying a small countersink or undercut may eliminate the need for a deburring operation to remove the heavy swell. The addition of a recess at the bottom of a blind broached hole can simplify burr and chip removal (Figure 16).

Relief on Machined Through Threads

Burrs formed by machining through threads are extremely difficult to remove. This problem can be eliminated by turning a relief diameter that is smaller than the minor diameter (Figure 17). The designer must indicate that these conditions are allowable or desirable through drawing notes or in-house standards.

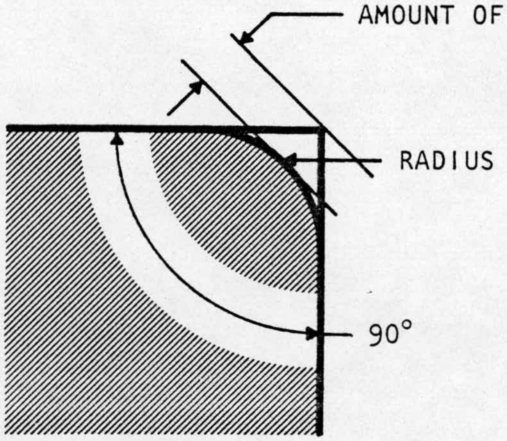
V-Grooves on Turned Parts

If a small burr is allowable on the outer diameter of a slotted part, an optional V-groove can be placed at the bottom of the slot (Figure 18). This groove permits the existence of a burr at



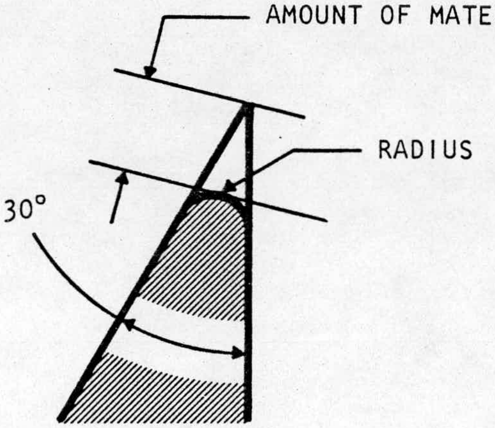
DIFFICULT

RADIUS		S	
INCH	μm	INCH	μm
0.002	50.8	0.0003	7.6
0.003	76.2	0.0004	10.2
0.005	127.0	0.0007	17.8
0.010	254.0	0.0015	38.1
0.015	381.0	0.0022	55.9



TYPICAL

RADIUS		S	
INCH	μm	INCH	μm
0.002	50.8	0.0008	20.3
0.003	76.2	0.0012	30.5
0.005	127.0	0.0021	53.3
0.010	254.0	0.0041	104.1
0.015	381.0	0.0062	157.5



LESS DIFFICULT

RADIUS		S	
INCH	μm	INCH	μm
0.002	50.8	0.0077	195.6
0.003	76.2	0.0116	294.6
0.005	127.0	0.0194	492.8
0.010	254.0	0.0387	983.0
0.015	381.0	0.0581	1475.7

Figure 12. Effect of Geometry on Edge Radiusing

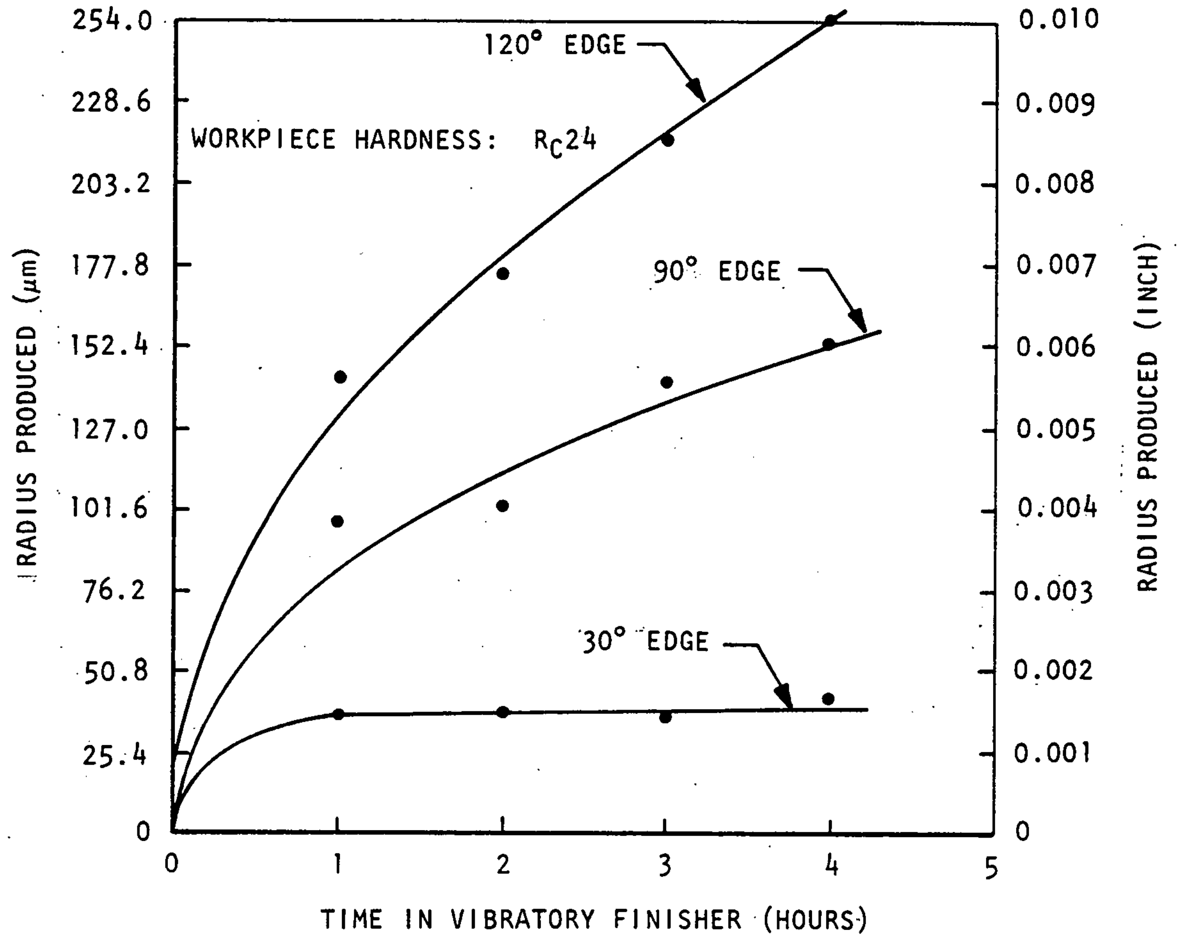


Figure 13. Effect of Edge Angle and Vibration Time on Edge Radiusing of Phosphor-Bronze Workpiece

the bottom of the slot without affecting outer diameter size. Although a small burr also forms at the sides of the slots, it may not be large enough to require removal. If it does, it is much easier to remove than the burr normally left at the bottom of the cut.

When a V-shaped groove is placed on the inside of a cylinder so that the cutoff tool will pass through this groove, the cutoff burr will not be as objectionable as on most parts. In this case, the improvement is the result of both the edge angle created by the 'V' and the fact that when properly placed, the burr will form down in the 'V' rather than up on the inner diameter. If total burr removal is required a vibratory operation should prove

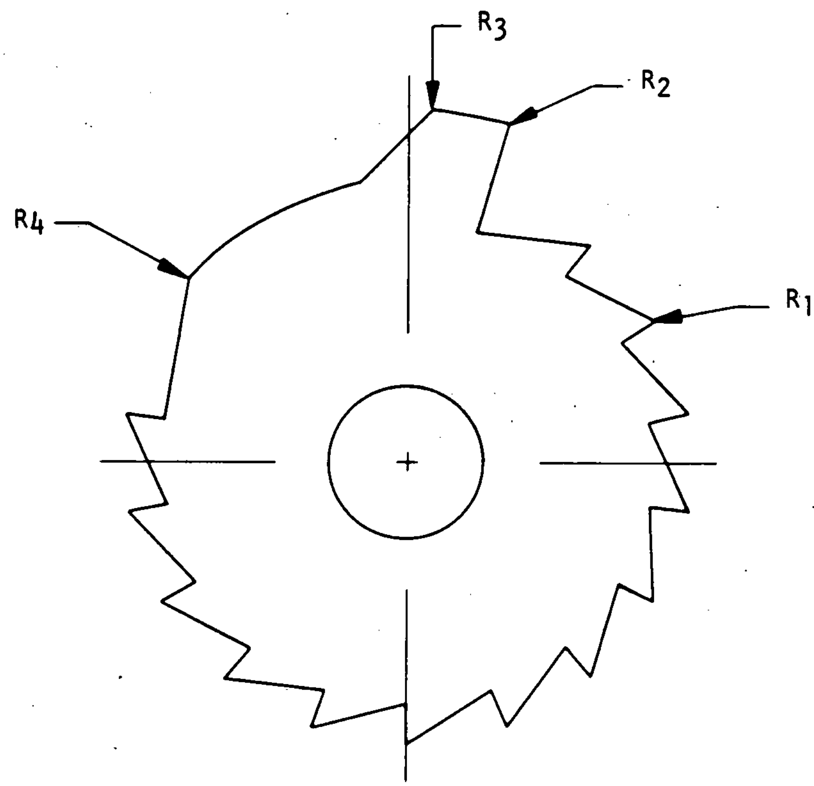


Figure 14. Example of Different Edge Angles on a Single Part

adequate. In this case, the designer may have to specify the allowable chamfer which the V-groove can introduce to the completed part.

Die Design Effects on Burrs

Part designs such as those shown in the left view of Figure 19 lead to early die wear because of the sharp edges required on the part. This in turn creates heavy burrs, particularly at the needle-like projections and cutouts. Designing per the guidelines shown in the right hand view extend die life and minimize burrs significantly. When sharp corners are necessary, they can be provided by ordering more expensive progressive dies.

Figure 20 illustrates a die-made part which could not be effectively deburred by vibratory or centrifugal barrel methods because the dimension b was reduced below allowable limits before the burr in

Table 1. Radii Produced on Three Edges of Part in Figure 14 While Maintaining Tolerance of Radius R_2 on Phosphor-Bronze

Radius Feature	Edge Angle (Degrees)	Radius Produced (μm)	Radius Produced (inch)
R_1	60	45.7 ±25.4	0.0018 ±0.001
R_2	90	127.0 ±25.4	0.005 ±0.001
R_3	125	287.0 ±25.4	0.0113 ±0.001
R_4	140	307.3 ±25.4	0.121 ±0.001

the holes was removed. Assuming the die is sharp, the solution in this case is to design the die so b is at its maximum size. The deburring process will reduce it while removing the burr from the hole. In this particular case, the two holes were drilled and the burrs were much larger than the burr produced from blanking. This example again emphasizes the need to coordinate deburring needs with initial tool design and process selection.

Designing for Easy Flash Removal

Since flash on die cast or molded parts has many of the same characteristics as burrs, many of the previous suggestions apply to flash, fins, and gates. Two additional rules; however, need to be observed for parts which will have flash on them:

- For appearance and ease of removal, parts should be designed so flash occurs at edges, or special features rather than on flat surfaces; and
- Gates should be designed to facilitate the removal of flash.

It is easier to predict the location and size of flash from die casting and molding processes than in machining because flash corresponds to die configuration rather than the path of a cutting tool. As a result designing to minimize flash is a technique which has been widely used for a number of years.

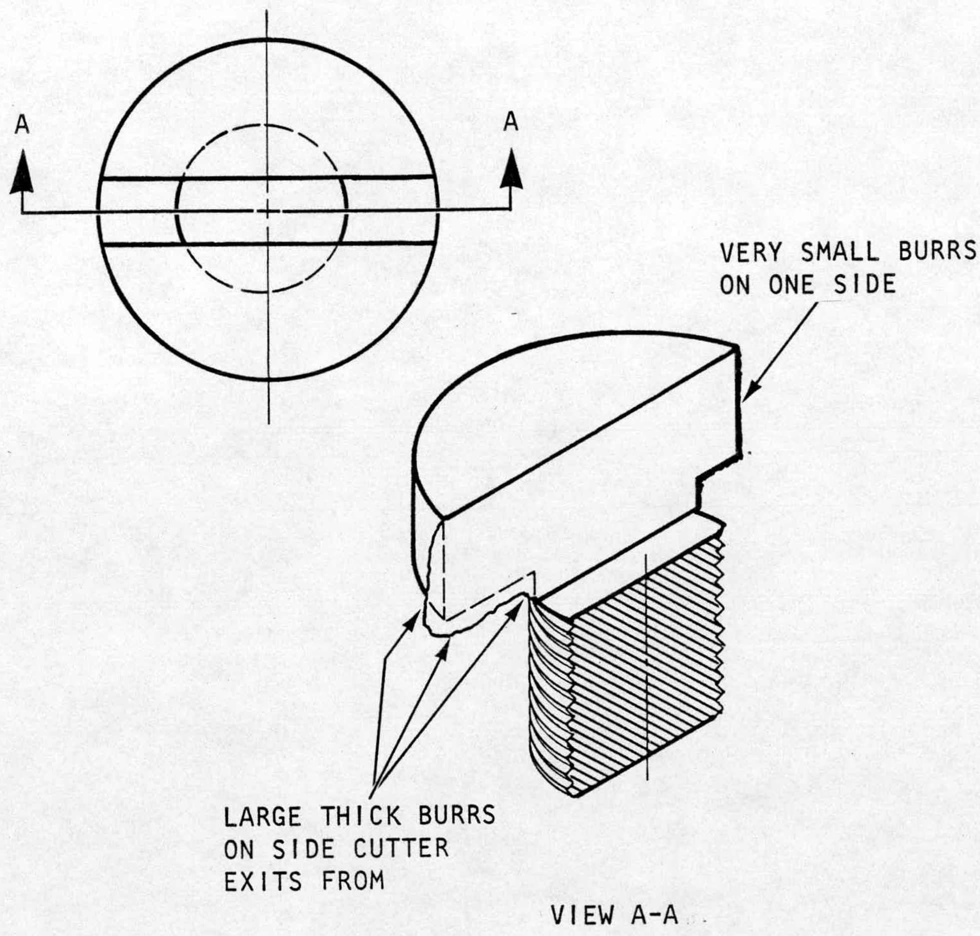


Figure 15. Slotting Through Flanges Makes Deburring Difficult

Figure 21 illustrates the first of these rules. Note that while the addition of the rib, roll, or bead around the part does not make flash removal any easier, it does help mask incomplete flash removal and slight offsets between the die halves. This can be an important consideration when aesthetics rather than function are involved.

One aspect of molded parts that simplifies deflashing is that generally trimming or clipping equipment which conforms to the part contour is used. This type of process attacks the flash and not the entire workpiece surface as is the case in vibratory deburring and abrasive jet deburring.

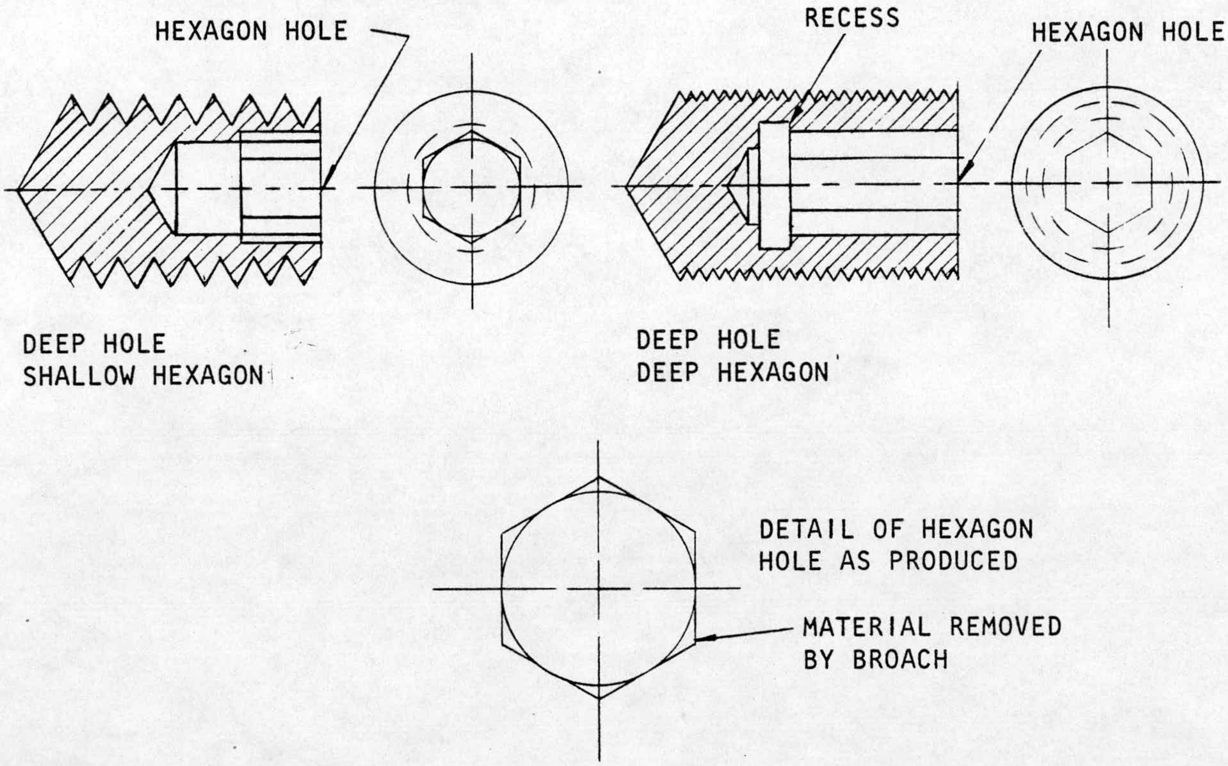


Figure 16. Provide Recesses in Blind Broached Holes

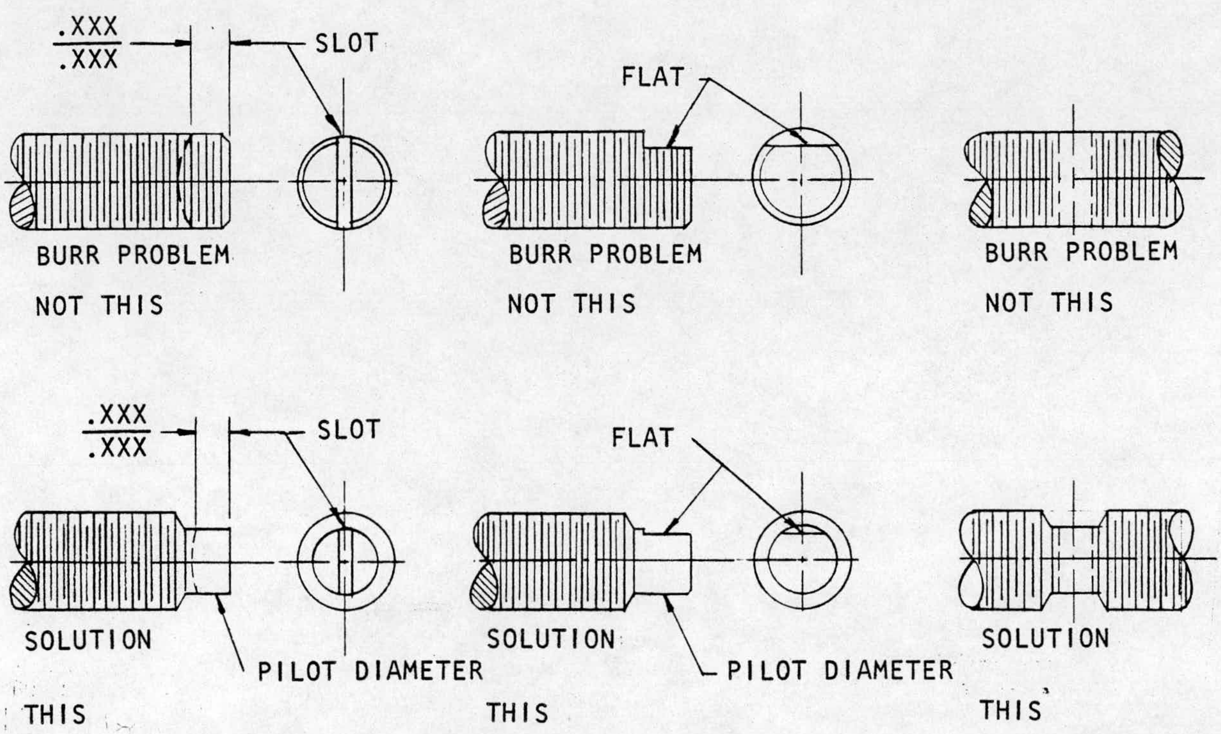


Figure 17. Use Thread Undercuts

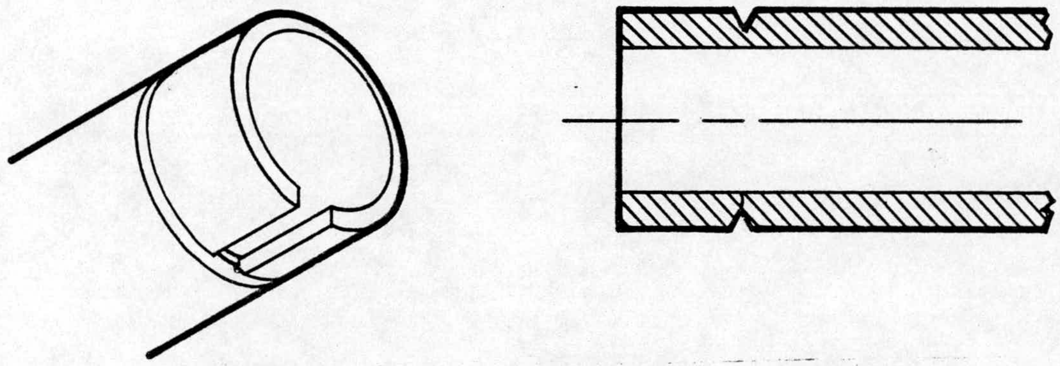


Figure 18. Use Groove to Minimize Milling Roll-Over Burr

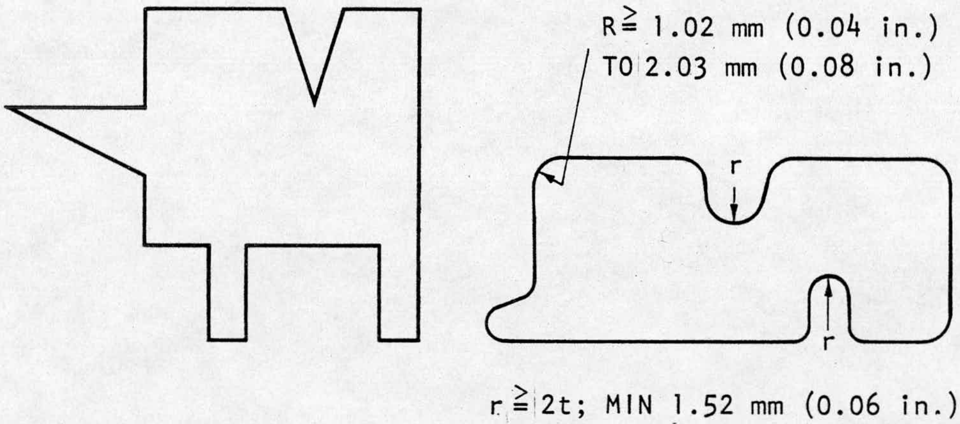


Figure 19. Use Large Radii on Blanked Parts

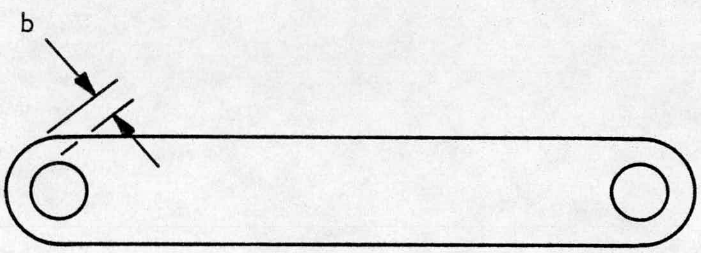


Figure 20, Die Should be Designed so b Will be Within Drawing Requirements After Deburring

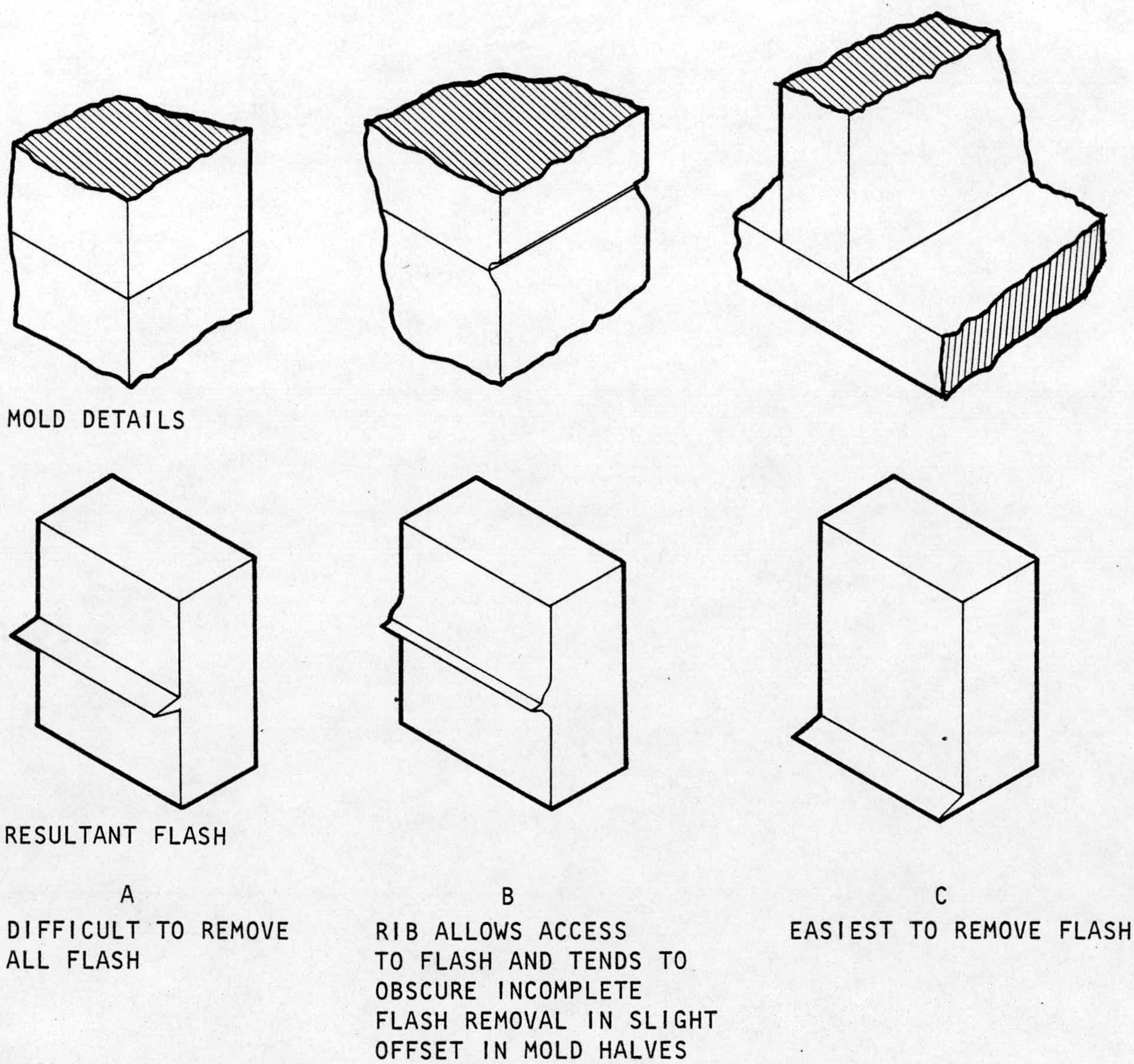


Figure 21. Effect of Flash Location on Ease of Removal

When surfaces must be ground to remove caps of flash around holes any projecting features should be recessed to provide an unobstructed grinding path (Figure 22). While piercing dies can be used to remove these caps they can result in tearing of the edges.

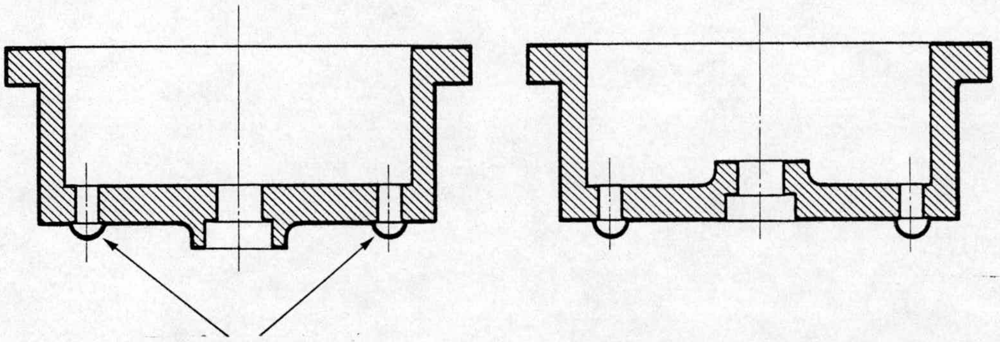


Figure 22. Design for Ease of Machining When Machining or Grinding is Required

Design considerations such as rolls and unobstructed surfaces are major factors in much of the aluminum, zinc, and plastic die casting industry since deflashing costs represent 20 to 35 percent of the total manufacturing cost.

The design of gating systems, ejector pins, and parting lines must all consider deflashing approaches. Overflow wells for example should be designed to allow the use of strong clipping punches (Figure 23). Figure 24 illustrates the desirable design features on compression molded rubber parts which are deburred by abrasive jet deburring.

Feather edges at the ends of threads should be avoided because they make mold fit more critical and promote flashing.

Gates should always have a shape which ensures that fracture of the gate occurs at the edge of the part (Figure 25); they should also be as thin as possible to get a clean fracture (Figure 26). With a shallow gate, the fracture is almost straight and follows the vertical face of the component, whereas a wider gate (center view) breaks on an insweeping curve which finishes at a point a few thousandths of an inch inside the correct line, shown chain-dotted.

Designing for Loose Abrasive Deburring Processes

While many designers may never know which deburring process will be used to remove burrs or flash, it is significant to note that at least 50 percent of all parts produced in the world are subjected to a loose abrasive deburring process such as barrel

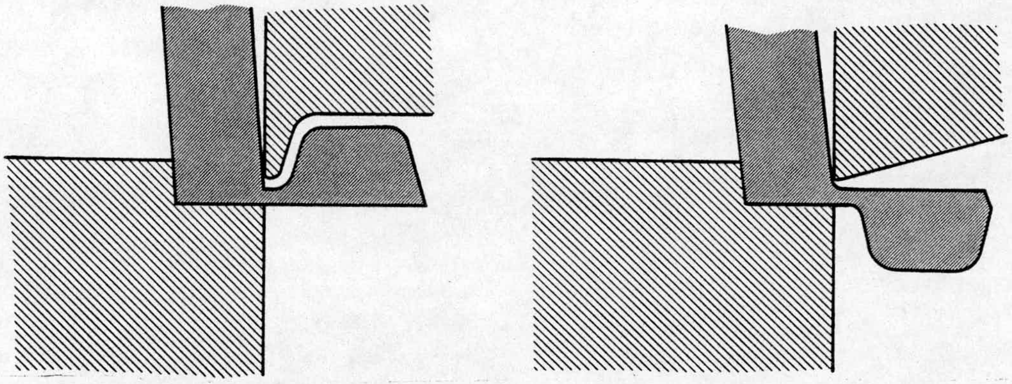


Figure 23. Designing Overflow Wells for Easy Trimming and Long Tool Life

tumbling, vibratory finishing, spindle finishing, or centrifugal barrel tumbling. Because these processes use the same basic deburring media and removal mechanism, a few considerations about design effects on them are in order.

The essential facts in these types of processes are:

1. The media must be able to slide over all surfaces which require deburring.

2. Large deburring media deburr faster than small media (except on very small parts).

3. The use of special preformed shapes such as triangles, stars, and cylinders have many advantages over gravel-like media.

As an example, consider Figure 27. In the left hand view the step height H_1 is smaller than the radius R_s on the deburring media which in this case is a triangle. As a result the media will often bend the burr over rather than remove it. Complete removal can be obtained only with long cycle times. The use of a larger step height as shown in the right hand view eliminates the problem since the media can work over the edge and against both surfaces. While the manufacturing engineer has a large choice of media sizes from which to choose, the smallest standard triangle

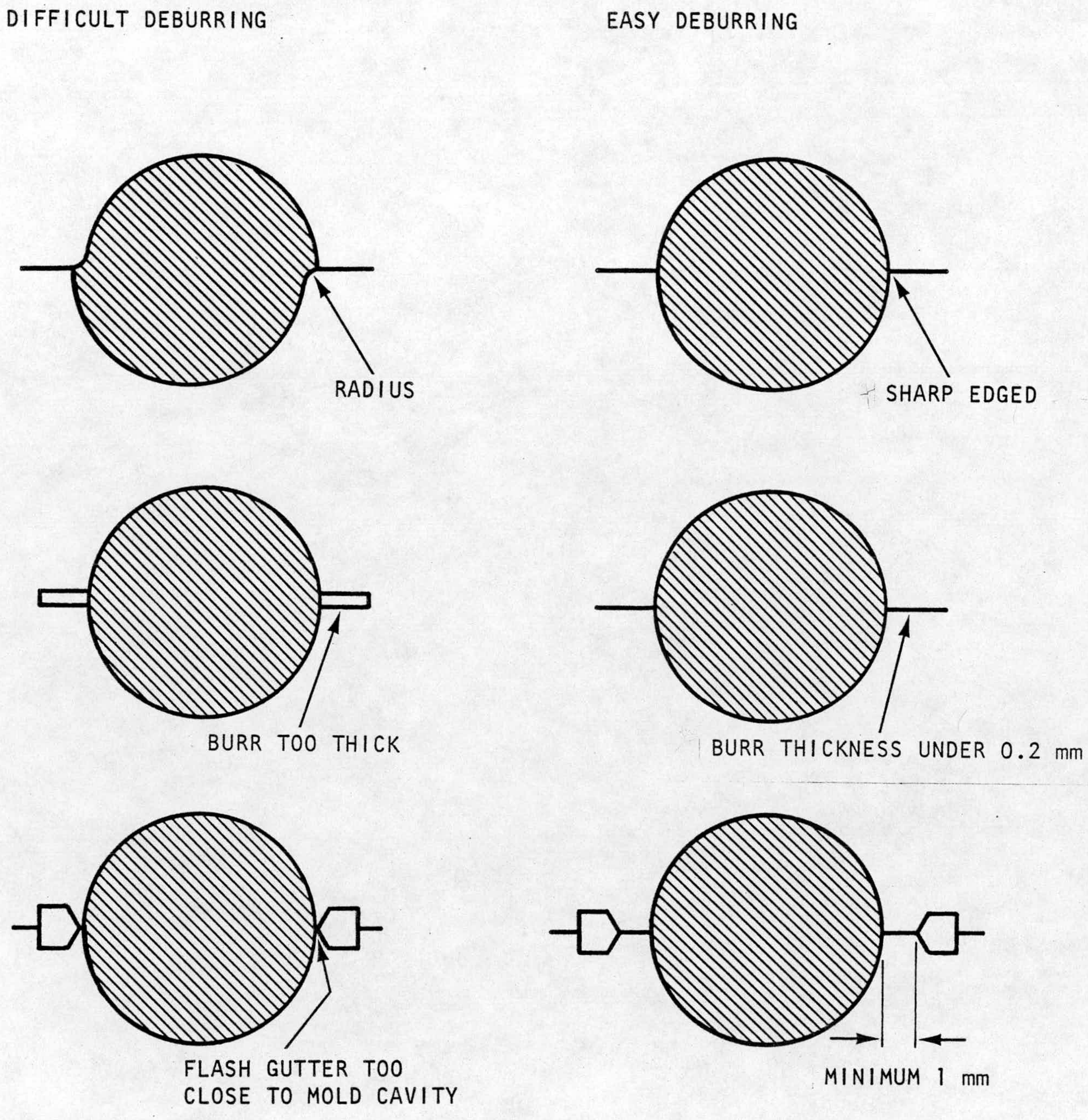


Figure 24. Design Considerations for Successful Deflashing of Compression Molded Rubber Components

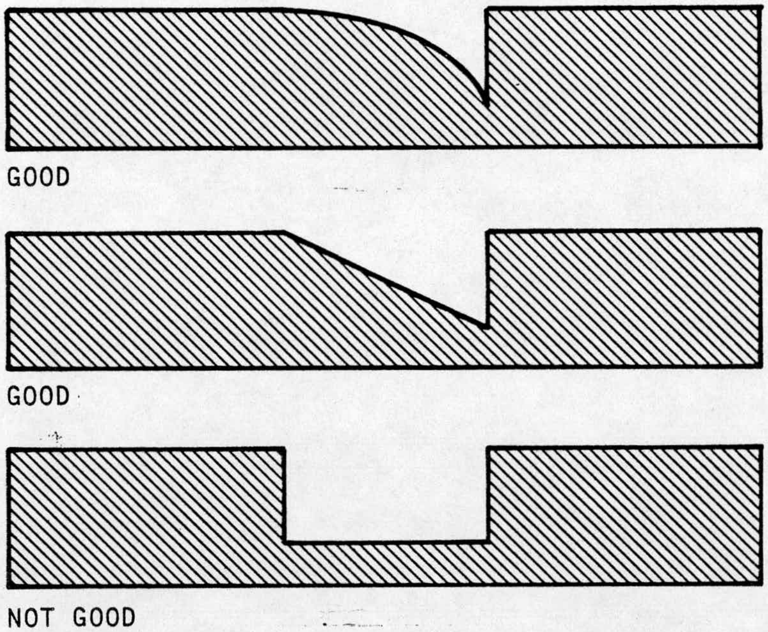


Figure 25. Gate Design

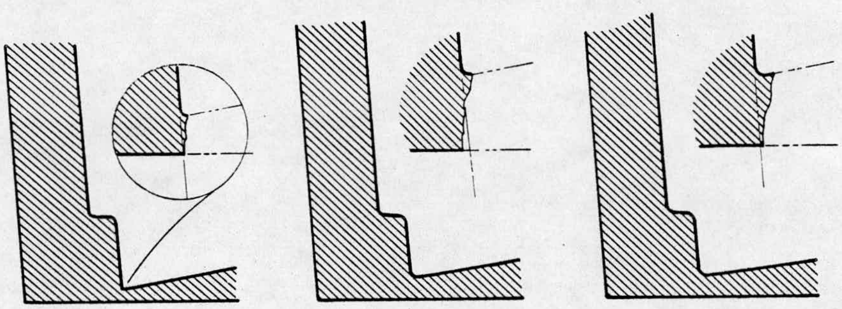


Figure 26. Effect of Gate Thickness on Edge Quality

available has a radius in the order of 0.040 inch (1 mm). As previously indicated it is frequently desirable to use larger triangles which have larger radii since they minimize deburring cycle times.

When the same edge radius and deburring quality is required on all edges of a part, processes which attack the entire workpiece surface may not be suitable. As shown in Figure 28, radiusing action is largest where the media can most readily contact the

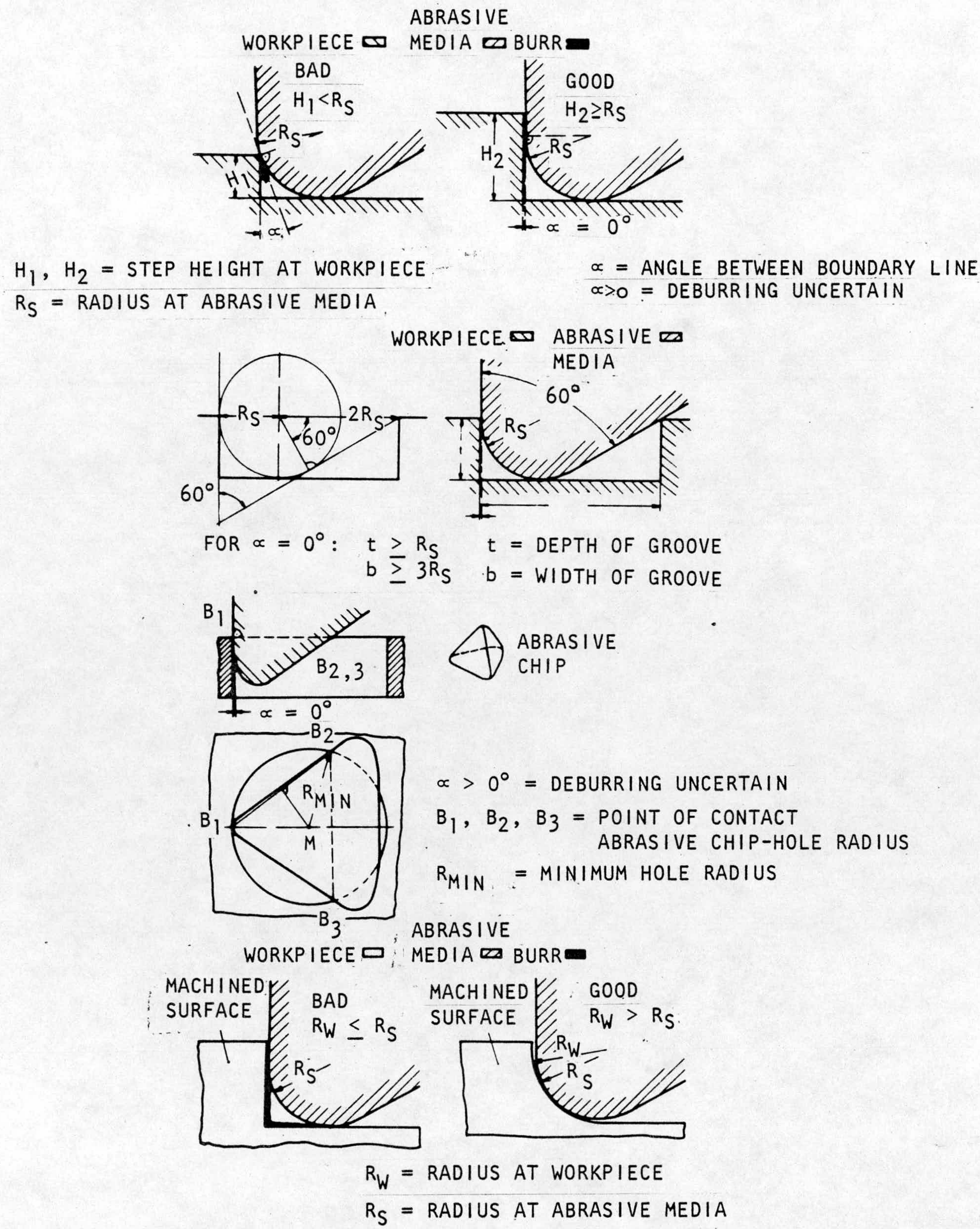


Figure 27. Complete Deburring Requires That the Angle $\alpha = 0$

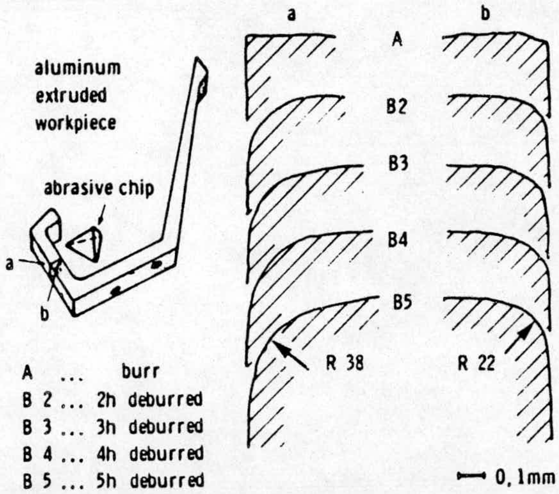


Figure 28. Effect of Workpiece Geometry on Edge Radiusing

part. The outside edge 'a' is accessible to all the media. Edge 'b' is partly shielded by the workpiece geometry. After a five hour run in tetrahedrons, edge 'a' had a radius of 0.015 inch (0.38 mm) while edge 'b' had a radius of only 0.0087 inch (0.22 mm). While such differences are not critical on some parts, they are on many others. The condition would be further aggrevated if the burr at 'b' were larger than at 'a'.

Each of the factors described thus far should be considered while parts are still in the design phase. While smaller deburring media or different shapes can be used, they create other problems. Whenever possible workpiece drawings should be reviewed by manufacturing engineers responsible for machining and deburring before the drawings are finalized.

Changing Workpiece Material Properties

The ductility of workpiece materials is a major contributor to burr size. Any technique which minimizes this property will minimize burr size. Materials such as copper, teflon, and the 300 series stainless steels typically have long and thick burrs. In contrast glass, ceramics, cast iron, and hardened tool steel have very minute burrs, if any, when they are machined.

The second material property which is a key to burr size is the strain hardening exponent n which is defined by:

$$\sigma = \sigma_o \varepsilon^n \qquad (1)$$

In this equation σ is the true yield strength of the material, σ_0 is a constant, and ε is the true strain in the specimen. High values of n (up to 0.5) typically indicate materials which will produce large burrs.

Design engineers frequently have considerable latitude in the materials which can be used in piece parts. Obviously if ductility and high values of n can be minimized at least during machining, deburring will be facilitated. If a specific material must be used which has undesirable (to the machinist) levels of ductility, then the use of various heat treat conditions may provide mutually suitable properties during machining. If necessary, surface hardening processes are available which limit hardening to just the surface skin (where the burrs form) or just to isolated portions of the skin. Subsequent annealing can be used to provide the desired final workpiece properties.

Controlling Workpiece Tolerances

As discussed in the first lesson very close tolerances limit the deburring processes which can be used. When tolerances are ±0.005 inch (±127.0 μm), any deburring process can be used with little concern about dimensions being changed by deburring. When tolerances are only ±0.0002 inch (±5.1 μm), great care must be taken to select the appropriate finishing process.

Specifying Edge Requirements

Probably the one area capable of the largest cost savings is that of specifying what edge requirements actually are. Although the product engineer is theoretically responsible for product definition, historically the manufacturing or quality engineers have assumed responsibility for indicating what is really required in the area of surface finishing. In the rush to get new products into production, actual requirements are often glossed over. The essential aspect in this phase is to be able to answer the following question affirmatively.

"DO YOU KNOW WHAT LEVEL OF QUALITY IS NEEDED?"

Answering this question opens a Pandora's box of subsequent questions. To answer the question affirmatively requires a knowledge of the component's and assembly's function. Then one needs to know just how critical each edge is to the function of the component and assembly. Most individuals assume without thinking that all edges should have the same edge radius or burr free condition. <u>In most situations this is not true</u>.

While in-house workmanship standards are a necessary requirement for most companies, they do not absolve designers from the responsibility of specifying actual requirements. In many cases deburring costs could be lowered if designers asked themselves (and found the answers to) the following questions:

IS A BURR ALLOWABLE?

- Would it cause an electrical short circuit?
- Would it jam a mechanism?
- Would it cause interference fits?
- Would it cause misalignment?
- Would it be a safety hazard? (Would it cut someone's finger during assembly?)
- Would it cause unallowable stress concentrations?
- Would it accelerate wear beyond allowable limtis?

The manufacturing engineer must also be able to answer the following questions:

- Why is burr free condition required?
- Why is _____ max. edge radii required?
- Where is burr free condition required?
- Where is _____ max. edge radii required?
- How is burr free condition measured?
- How is edge break condition measured?
- What happens if a part is not burr free?
- What happens if a part does not have _____ max. edge radii?
- How can a part be redesigned to minimize the burr?

For many designers, manufacturing engineers, and inspectors the task of defining what is allowable has been difficult. The following approaches however have been used successfully by many large and small companies.

METHODS OF DEFINING AN ALLOWABLE BURR OR EDGE CONDITION

- Define it on the print,
- Define it in a Process Engineering Specification (Manufacturing Specification),
- Define it on the production traveler (routing sheets),
- Define it by interpretive memo. Such a memo could include sketches, photos, measuring techniques, etc.,
- Define it on the inspection traveler,
- Define it with photos of acceptable and unacceptable conditions,
- Define it by the use of comparative masters (the master is given a tool or gage number, or a visual aid or visual standard number),
- Define it by go-no go. If it fits the gage, the burr is acceptable,
- Define it by taking specific exception to general workmanship specifications, and
- Define it by such phrases as "Firmly adhered burrs or raised metal is allowable in this area provided a micro tool 90° hook will not dislodge them."

Figure 29 illustrates a technique for graphically defining allowable edge quality. As seen in the right hand view, the system has nine classes of quality. Class one allows projections up to 0.01 mm (0.0004 inch). Class nine allows projections or radii up to 2.50 mm (0.10 inch). The symbols r_k, h_1, and b_k are defined in the left hand view. As seen there, r_k indicates the size of radius allowed, bk indicates either a radius or the size of chamfer allowed, and h1 indicates the height of a projection which can be allowed. The left hand view also shows the many types of conditions that can be found at an edge. If one extended the planes of the workpiece surface, four quadrants are produced. It is possible for a burr to exist in any of these. It is also possible that as a result of edge deformation material can exist in more than one quadrant (Figure 30).

To illustrate the system, consider a 0.3 mm (0.012 inch) radius on an edge (Figure 30 upper left). From Figure 29 this falls within the range 0.16 to 0.315 mm and is thus a class six edge.

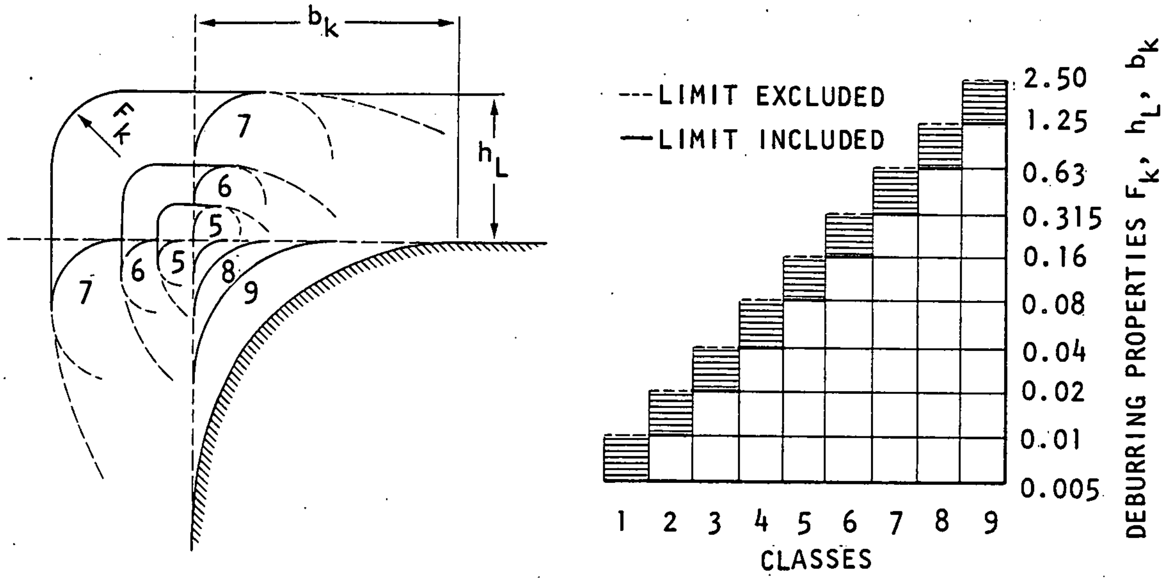


Figure 29. Classes of Allowable Edge Quality Proposed by Schafer

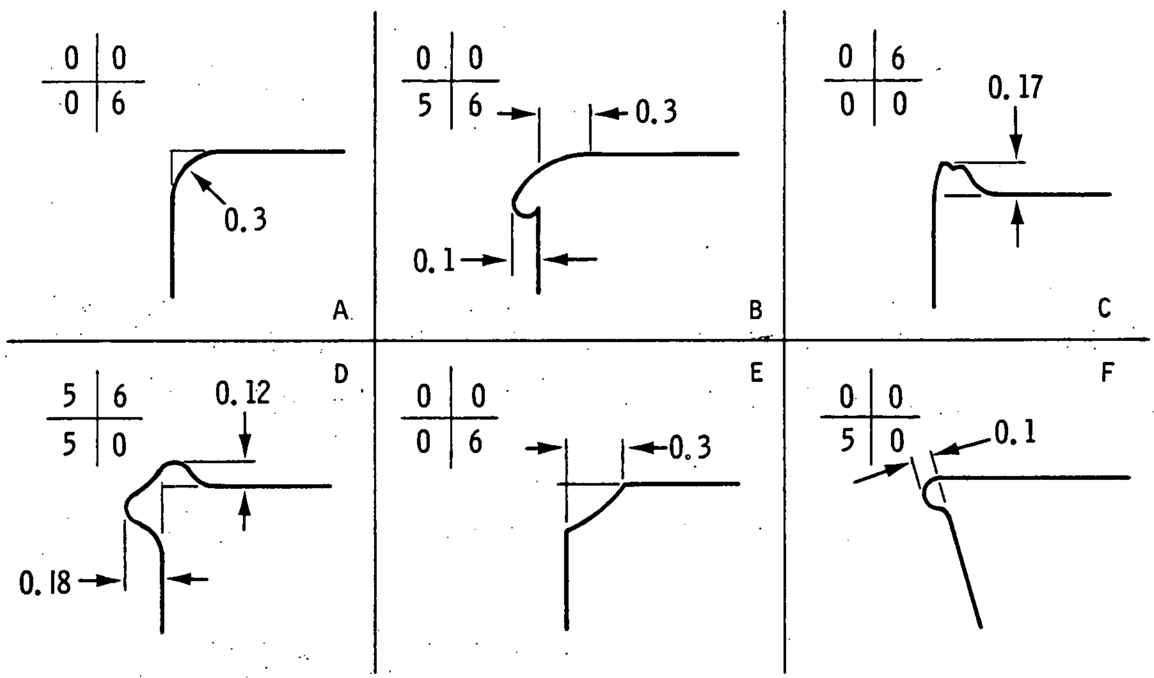


Figure 30. Edge Conditions and Related Notation

Since it is a radius occurring in the fourth quadrant (the quadrant which the workpiece itself is in) the edge specification is

$$\begin{array}{c|c} 0 & 0 \\ \hline 0 & 6 \end{array}.$$

The upper right hand view shows a 0.17 mm (0.007 inch) high burr. This too falls within the range of a class six edge. In this case the burr projects into the first quadrant. Since the workpiece is always in the fourth quadrant for the position shown, anything in another quadrant must be a burr. Thus,

$$\begin{array}{c|c} 0 & 6 \\ \hline 0 & 0 \end{array}$$

indicates a burr which is between 0.16 and 0.315 mm high extending into the first quadrant.

The upper middle illustration portrays the case where a burr is in the third quadrant but some radiusing exists on the part. In this case edge quality number exists in two of the four quadrants.

This system can be used on edges with included angles less than 90° (Figure 30F). In this case however b_k is not equal to the radius r_k as is the case with 90° edges. When edge angles are different than 90° there will be two big and two little quadrants.

Figures 31 and 32 illustrate a simple system for defining the allowable presence of burrs. The letter 'B' on an extension or dimension line indicates that a burr is allowable along this edge. An arrow indicates the direction in which the burr is allowed to project. If direction is not critical, no arrow appears. A dimension beside the 'B' indicates the maximum allowable height of the burr.

When systems such as shown in Figures 30, 31, and 32 are not feasible, one may have to depend upon drawing notes. While notes such as shown in Figures 33 through 35 may be adequate for parts made within a specific plant, they should be avoided if parts are to be made by outside vendors. Sooner or later the product designer will be asked to define "small burr." A 0.005 inch (127.0 μm) tall burr is small on a farm plow, but it is big on a 0.016 inch (406.4 μm) diameter precision miniature screw.

Figures 36 through 40 illustrate the preferred practice for specifying edge quality. Allowable burr sizes are described in Figures 36 through 39. Although chamfering produces a small burr, it is generally smaller than the burrs produced by the other processes and thus chamfering may represent all the deburring

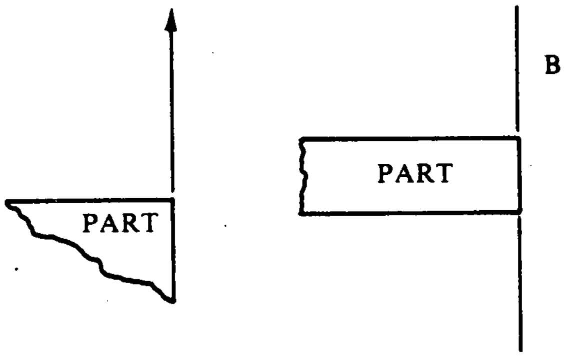


Figure 31. One System for Defining Where Burrs are Allowable

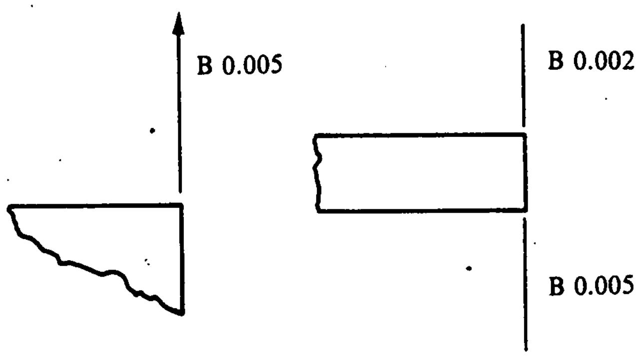


Figure 32. A System for Defining the Size of a Burr Which is Allowable

which is required. Either drawing notes or an in-plant standard should be used to indicate whether chamfering represents adequate deburring. When a smooth blend is required, it should be specified as a radius. Edge breaks (chamfers) should be so specified that either a chamfered or a radiused condition is allowable. This allows the manufacturing engineer to determine whether a machining or a deburring process will provide the most economical edge condition. Typical corner breaks are 0.015 inch by 45° (0.397 mm by 45°) or 0.010/0.015 inch by 45° (0.254/0.381 mm by 45°). Radii should not be specified larger than 0.010 inch (0.254 mm) nor smaller than 0.003 inch (76.2 μm).

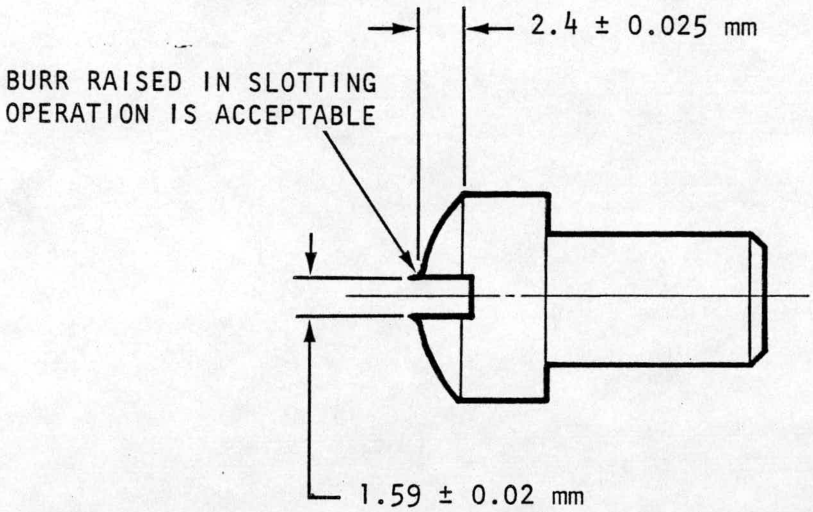


Figure 33. Note for Slotting Burrs

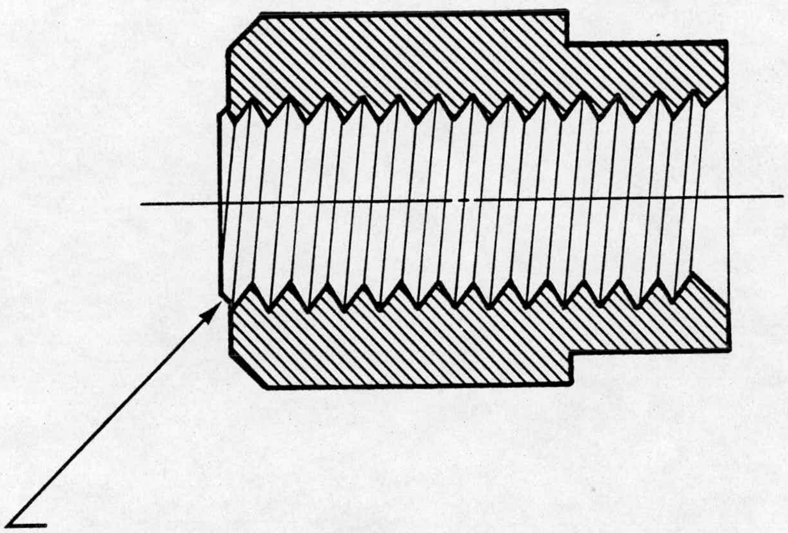


Figure 34. Note for Tapped Hole Burrs

The direction a burr faces is sometimes more critical than its actual size. In these cases, the orientation of the part should be noted on the drawing (Figures 39 and 40). In the case of symmetrical threaded parts, it is helpful to the manufacturer if the designer indicates which end of the part the screw is started from. This may eliminate the need to deburr both ends.

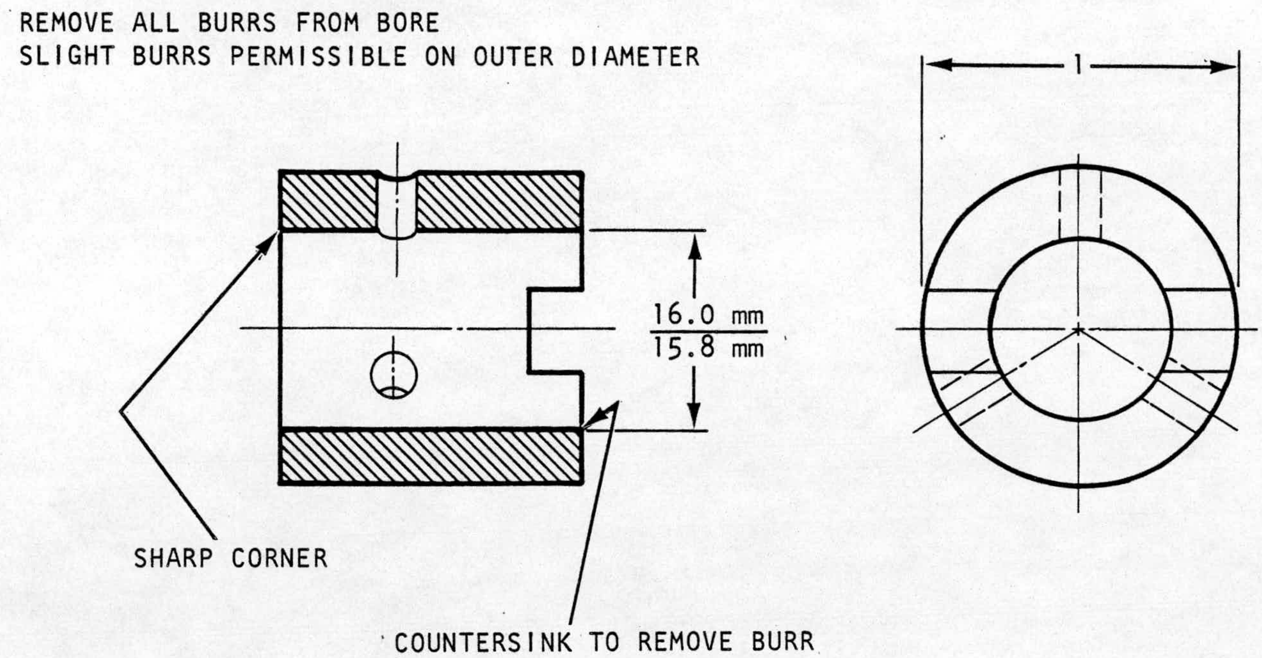


Figure 35. Burr Notes

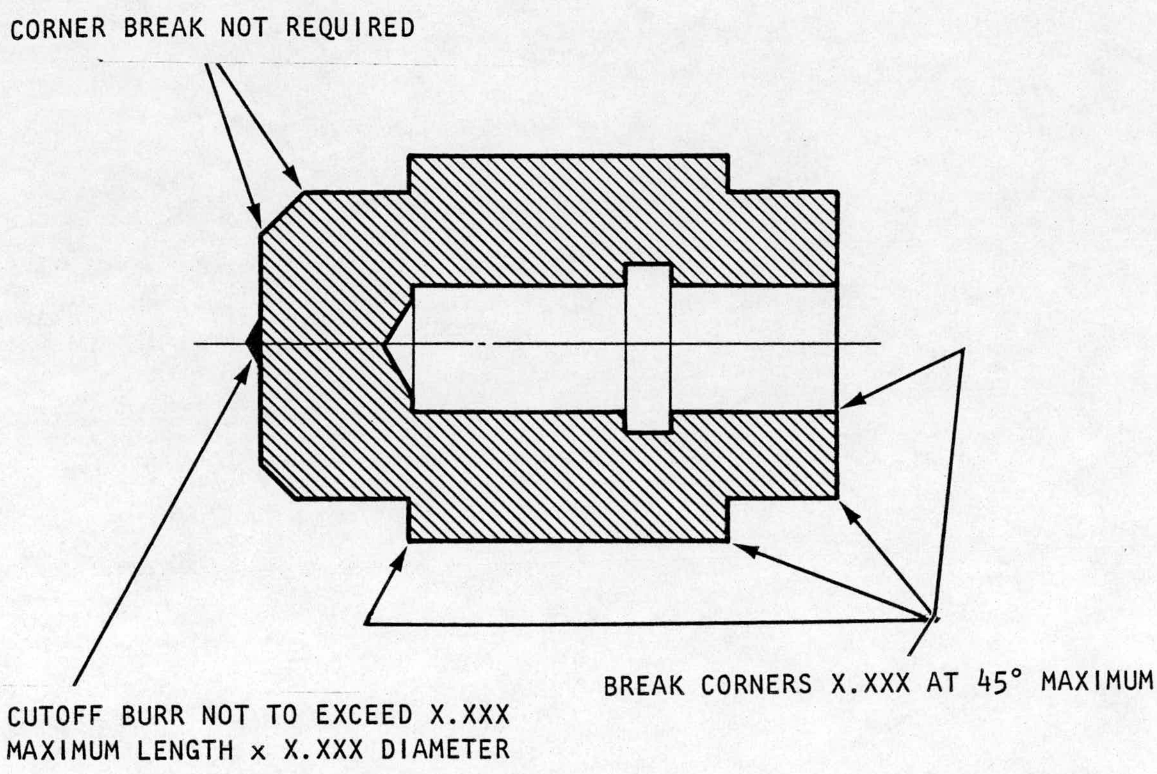


Figure 36. Typical Burr Notes for External Edges

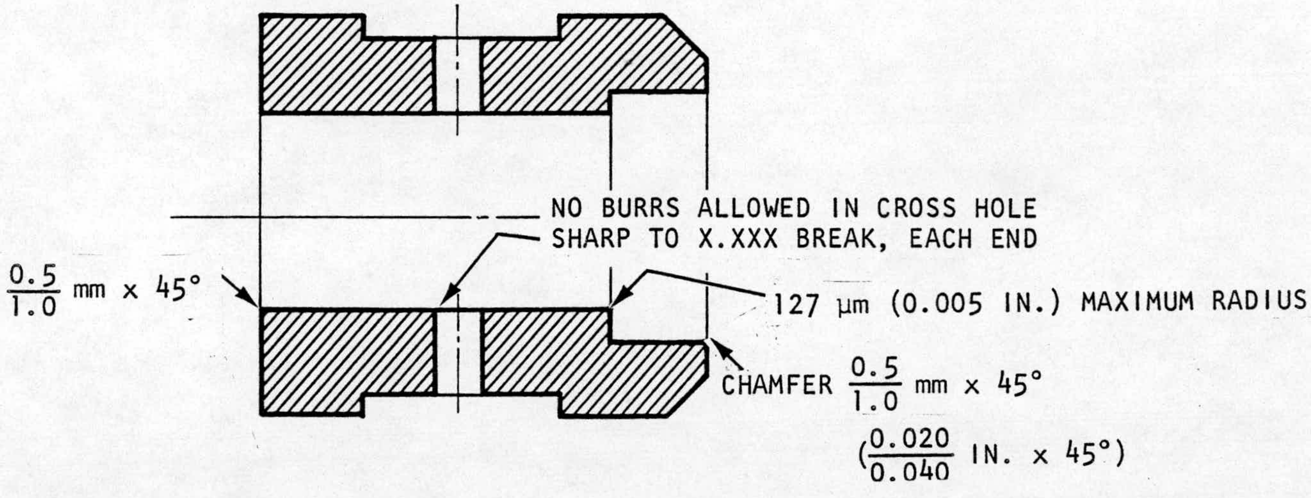


Figure 37. Typical Burr Notes for Internal Edges

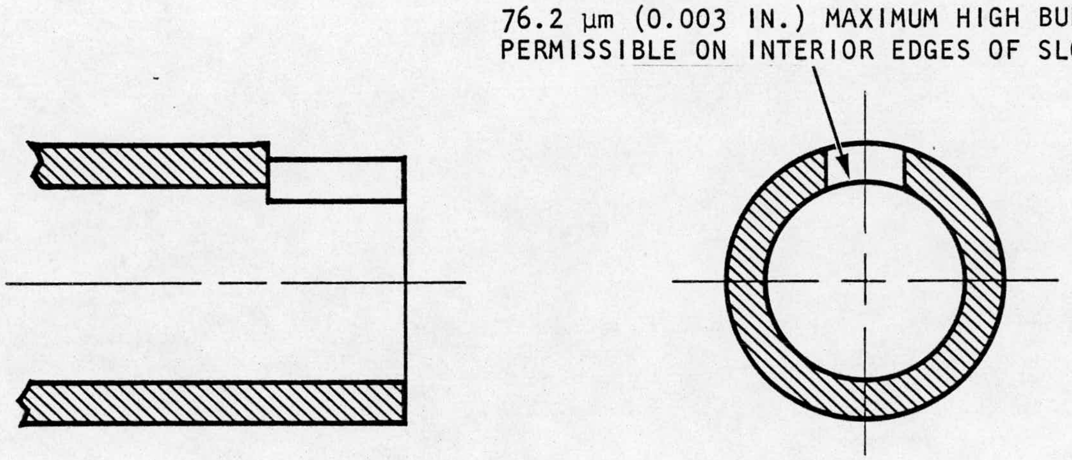


Figure 38. Define Allowable Burr Size and Location on Intersecting Features

A burr always forms at the intersection of two holes. If a burr cannot be tolerated in one hole, but can in the other, this must be noted (Figure 40). Defining where burrs can exist on formed parts may eliminate the need to deburr the sheet stock. With proper thought and communication between product designer, tool designer, and manufacturing engineer, forming dies can be designed so burrs on the blank will be in an out-of-the-way location in the finished part.

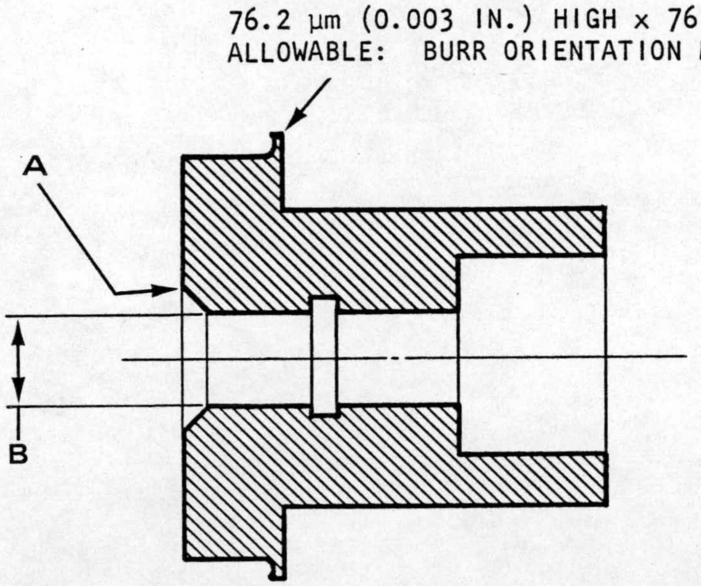


Figure 39. Define Allowable Burr Size and Location on Simple Parts

On many parts, the only significant edge requirement is that all sharp edges be removed. In this case, beating over burrs and dulling edges is adequate. The sole plates on some vacuum sweepers are treated in this manner. Designers can handle these situations in at least two ways:

- By specifying the process which gives an acceptable edge; and
- By defining the actual edge quality needed.

Vibrating parts in steel balls will dull the edges of most parts very economically. Similarly, thermal energy deburring (TEM) can be used to assure that no loose burrs or particles will be present to jam assemblies. While specifying on the drawing that parts shall be vibrated in steel balls to dull edges is often done for parts made within a plant, such notes are not complete enough for work contracted to others. Others must know what size ball, how long to run, and the amplitude and frequency of the machine to be used. These can be specified by developing explicit processing standards and referring to them on the part drawings. Such an approach is easy and relatively problem-free when the majority of parts have similar requirements.

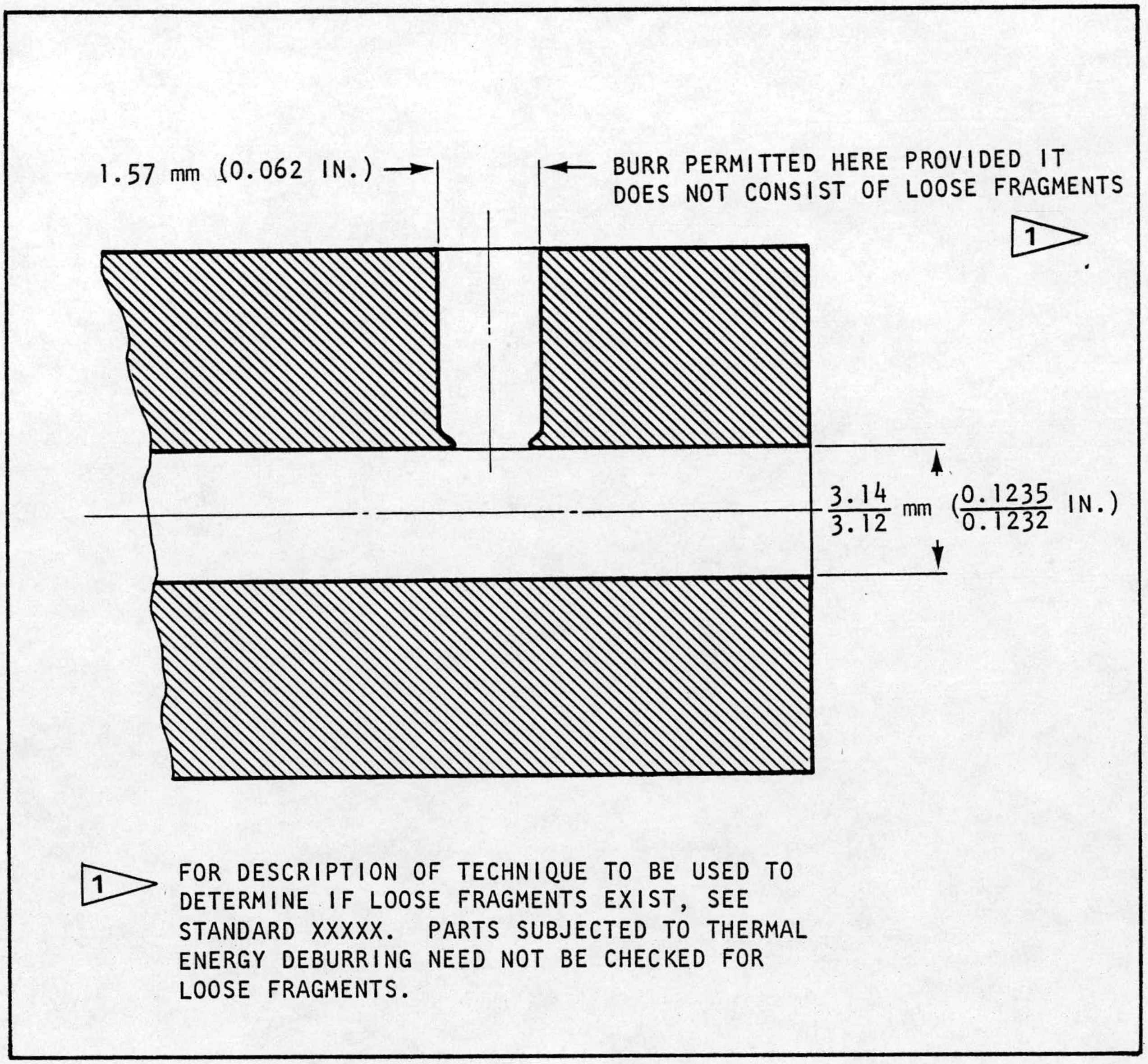


Figure 40. Define Allowable Burr Size and Location at Hole Intersections

When a wide variety of parts is designed and manufactured every year, this technique may restrict the manufacturing engineer's ability to make parts by the least expensive process. For example, a standard may specify that abrasive blasting be used. On some parts, a centrifugal barrel finisher might be noticeably more economical. Although drawing notes can be changed, the paperwork and delays involved add unnecessary costs. Five different manufacturers may have five different approaches to providing the same edge quality. Each uses the cheapest method at that time.

Standards for Inter-Company Use

In many instances, problems in communication are more between companies than within an individual company. Small job shops in particular suffer from some of these problems when they must manufacture parts for a wide variety of other companies. In such situations it is useful to have a quick handout defining that company's policy or the joint policy of the two companies in establishing their related quality levels. In such situations the handout shown in Figure 41 provides the talking point which both parties can use. In some situations the vendor or subcontractor need only circle the alphanumeric entities appropriate to individual parts or groups of parts. As shown in these Figures, one needs:

- A statement of edge quality requirements;
- A definition of what burrs are; and
- A definition of what constitutes sharpness.

Exceptions to these general standards would be defined on individual drawings. An alternative is to publish a booklet describing in detail burr related expectations.

Standard Definition of "Company Name" Allowable Edge Conditions

Category Number	
1	Deburring not required.
2	Remove all loose particles.
3	Dull all edges for handling safety.
4	Burrs and raised material are allowable provided they do not extend past part tolerance limits.
5	Raised material is allowable provided it does not extend past tolerance limits and is not sharp.
6	Burrs visible to the naked eye are not allowable, except as noted.
7	Burrs not detected by a sharp number 2 wooden pencil are allowable.
8	Burrs or raised material visible at 4X magnification are not allowable, except as noted.
9	Burrs or raised material visible at 7-10X magnification are not allowable, except as noted.
10	Burrs or raised material visible at 20X magnification are not allowable except as noted.

Burrs are defined as:

A. Any plastically deformed material at an edge generated by a chip producing process. This includes non-sharp raised material.

B. Any loose or semi-loose material left on edges by a chip producing process.

C. Any sharp raised material at an edge produced by a chip producing process.

Sharpness is defined as:

+ The ability to cut hands in normal handling.

- Failure to pass the Underwriter's Laboratories sharp edge tester test.

* Edge breaks smaller than 0.001 inch. (25.4 µm)

— Edge breaks smaller than 1/10 the thickness of the part (i.e. on a 0.005 inch thick (127.0 µm) part, a sharp edge is any edge having a radius or chamfer smaller than 0.0005 inch).

Figure 41. Sample Handout for Use in Designating General Level of Deburring Quality Required

Standard Definition of "Company Name" Allowable Edge Conditions (continued)

Example for Use of These Codes

On part number 299971, the allowable edge conditions are your company code number "5A*, .015 inch maximum break." This defines for both you and your customer what he wants, what burrs and sharpness are defined to be and what the maximum allowable edge break is. Exceptions to these allowable conditions would be stated by special callouts on the customer's part drawings.

Figure 41 Continued. Sample Handout for Use in Designating General Level of Deburring Quality Required

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[3]Federico Strasser, "How Control of Burrs Aids Sheet Metal Stamping," *Iron Age*, January 21, 1960, pp. 90-92.

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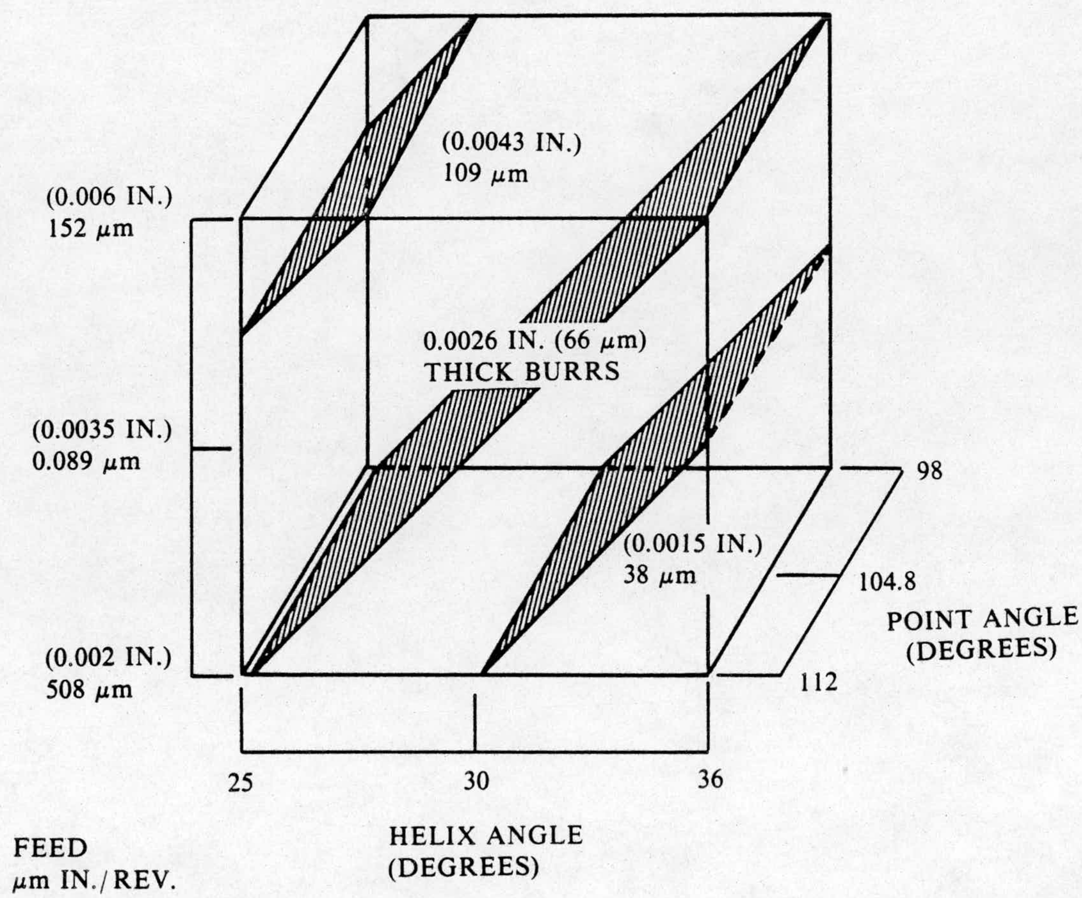
Deburring: Technical Capabilities and Cost-Effective Approaches

by LaRoux K. Gillespie

Lesson 4
Burr Prevention and Minimization



SUMMARY

The nontraditional machining processes are the only machining approaches that can be used to prevent burrs, but their use is contingent upon such factors as workpiece tolerance, geometry, surface integrity, and availability of such equipment.

Burr minimization is always possible. For effective use of this approach; however, it is essential to have a knowledge of how burr size affects deburring costs. Changing feeds and speeds will reduce burr size, as will selecting appropriate cutters, using backup material, and choosing workpiece materials which have low ductility and strain hardening exponents. Burr removal can be expedited by placing burrs in a position in which they can easily be removed. Using different machining sequences can also minimize the amount of deburring required.

LESSON 4

BURR PREVENTION AND MINIMIZATION

If burrs could be prevented from forming then deburring would not be required. Unfortunately altering speeds, feeds, and tool geometries will not prevent burrs. Both analytical and empirical studies have shown that while tool sharpness and cutting conditions can minimize burr size and control burr repeatability, they cannot prevent burrs. Conventional machining techniques always produce burrs.

Burrs can be prevented by:

- Using some non-traditional machining processes;
- Employing appropriate angles on the workpiece; and
- Employing radically different production techniques.

Small burrs are obviously much easier to remove than large burrs. The use of burr minimization techniques is one of the easiest approaches one can use to lower deburring costs. Burrs can be minimized by:

- Changing part configuration;
- Changing tool configuration;
- Changing feedrates;
- Changing cutting velocities;
- Changing machine stiffness;
- Changing type of machining operation;
- Minimizing cutting forces;
- Selecting more appropriate workpiece materials;
- Using backup material; and
- Better fixturing of parts.

In addition, burrs can be effectively minimized by just changing their location such that they are easier to remove.

BURR PREVENTION

As seen in the first list in this chapter, there are relatively few approaches one can use to prevent burrs from forming.

While all conventional machining processes produce burrs, burrs can be prevented by employing some of the nontraditional processes. As seen in Table 1, most of the nontraditional processes do not produce burrs. Despite many statements to the contrary, EDM, EBM, and Laser Machining (LBM) do produce burrs or burr-like projections of recast material. Recent research on LBM indicates that when a high velocity air blast is synchronized with the laser the majority of the recast is blown out before it can solidify on the workpiece. Thus in the future, LBM may fall in the category of processes which do not leave excess material at edges.

Whenever possible processes such as CHM, ECG, ECM, ECH, ELP, and ESM should be used. They not only eliminate deburring costs but they also provide excellent surface finishes and minimize welding, brazing, and plating problems caused by media impregnation or improper cleaning. In addition the elimination of unnecessary operations reduces paperwork costs and shortens production flow time.

In many cases the disadvantages of using the nontraditional processes include high equipment costs, limitations to certain geometries, workpiece materials, and workpiece tolerance and surface integrity problems. These factors are discussed in detail in many other texts.

As seen in Lesson 3, some burrs can be prevented by the correct choice of edge angles. While this approach to burr prevention should be pursued, it does not solve the total deburring problem as many cutting tools produce burrs on many edges with a single pass. It is not feasible to prevent these burrs on all edges.

The last item in this list includes several emerging approaches. As an example of the third burr prevention technique, consider high speed machining. High speed machining (cutting velocities in excess of 10,000 surface feet per minute [51 mls]) has been observed to produce no burr in some metals. At the present time the validity of this claim is only known to a few people. In many cases in the past, a claim of 'no burr' actually meant a much smaller burr or 'no burr of consequence' to most users.

In the case of high speed machining, there is good reason to believe that burrs might not be visible or detectable with fingers. Figure 1 illustrates some typical curves of ductility and energy required to fracture specimen as a function of testing velocity. In this case the results are for tensile testing flat coupons.

Table 1. Nontraditional Machining Capabilities

Process	Typically Makes Burr?*	Typical Edge Radius Produced (inch)**	Typical Machining Tolerance (inch)
AJM Abrasive Jet Machining	No	0.003	
CHM Chemical Machining	No	Unknown	±.002
EBM Electron Beam Machining.	Yes	--	±.001
ECDM Electro Chemical Discharge	Unknown	Unknown	Unknown
ECG Electro Chemical Grinding	No	0.003	±0.002
ECM Electro Chemical Machining	No	0.001	±0.002
ECH Electro Chemical Honing	No	0.0005	±0.0002
EDM Electrical Discharge Machining	Yes	--	±0.0006
ELP Electropolishing	No	0.001	±0.0005
ESM Electro Stream Machining	No	0.002	±0.001
HCG Hot Chlorine Gas	No	0.002	±0.003
IBM Ion Beam Machining	No	0.00005	±0.0001
LBM Laser Beam Machining	Yes	--	±0.001
PAM Plasma Arc Machining	Yes	--	±0.003
USM Ultrasonic Machining	No	0.001	±0.001
WJM Water Jet Machining	No	Unknown	±0.003

*Where burr is visible under 30X magnification.

**0.001 inch = 25.4 μm

Similar results have been obtained for cylindrical specimen. The same basic patterns have been observed to occur in blanking operations.

In each case a metal has a critical velocity above which less energy is required to induce failure or separation. Lower energy requirements are the result of smaller amounts of plastic deformation which is the cause of burrs. In the case of 17-7 PH stainless

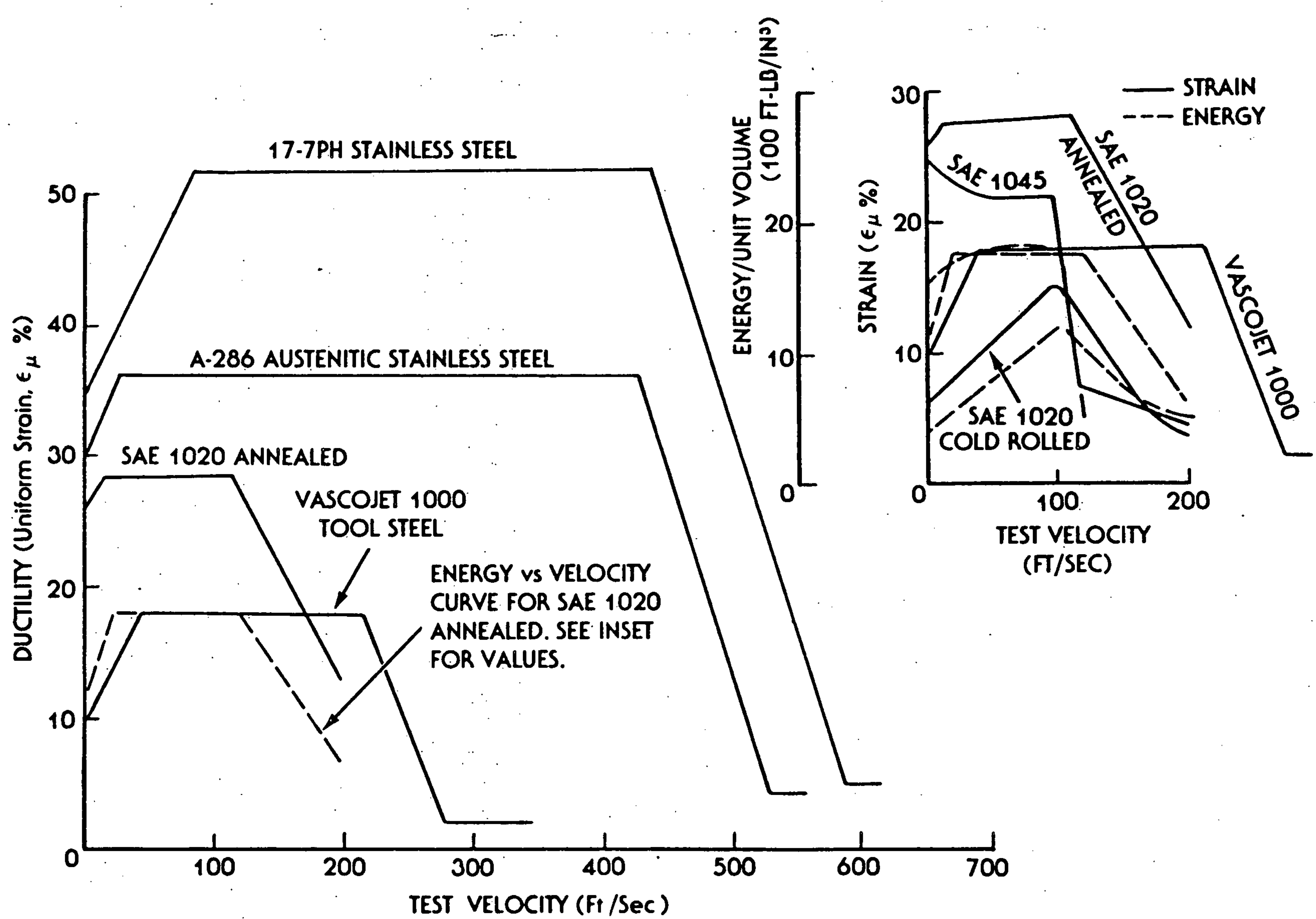


Figure 1. Energy Requirements as a Function of Test Velocity

steel, at 600 feet per second (183 m/s) the ductility of the specimen tested as 1/7 of its normal amount. It was 1/10 of that required at 100 feet per second (30 m/s). Thus it is highly plausible that burrs could be effectively prevented by high speed machining.

In a related view, it is obvious that we have much to learn about machining characteristics in unusual environments. If tornadoes can drive wheat straws through telephone poles, it is not difficult to believe that combinations of high velocity and unusual environments will be able to prevent burrs from forming. The key to burr prevention is to prevent plastic deformation from occurring macroscopically at part edges. Any environment which prevents this will minimize or prevent burrs.

Today researchers are investigating the potential of nontraditional coolants such as liquid mercury to improve machining. There is some hope this will help minimize or prevent burrs since it tends to remove surface ductility and help breakup chips.

A simple technique which has been used to prevent burrs is to extrude complex sections rather than machine them. This saves greatly on machining costs and the only burrs formed are at cut off edges.

Burr size can be controlled or prevented on some machines by three additional approaches.

- Use a form tool to form diameters. No burr can form when the tool produces the diameter and the adjoining face at the same time (Figure 2). Any intermediate burr formed is wiped off.

- Break all edges with a chamfering tool. Since tool position can accurately be controlled to 0.0002 inch (5.08 μm) on many materials, the chamfer tool can remove the burrs and still assure small final edge breaks. Chamfering precision miniature stainless steel components typically produces burrs smaller than 0.0005 inch (12.7 μm).

- Generate corner radii by cam design. While the cutting tool can be programmed to cut radii at edges, it is difficult and severely limits the adjustment capability of tools producing adjacent features.

As a general rule, Swiss automatic screw machines which hold tolerances of less than 0.0005 inch (12.7 μm), fillet radii of 0.003 inch (76.2 μm) or less, and finishes of 32 microinch (0.8 μm) or better in stainless steel will produce burrs less than 0.001 inch (25.4 μm) thick and 0.001 inch (25.4 μm) high.

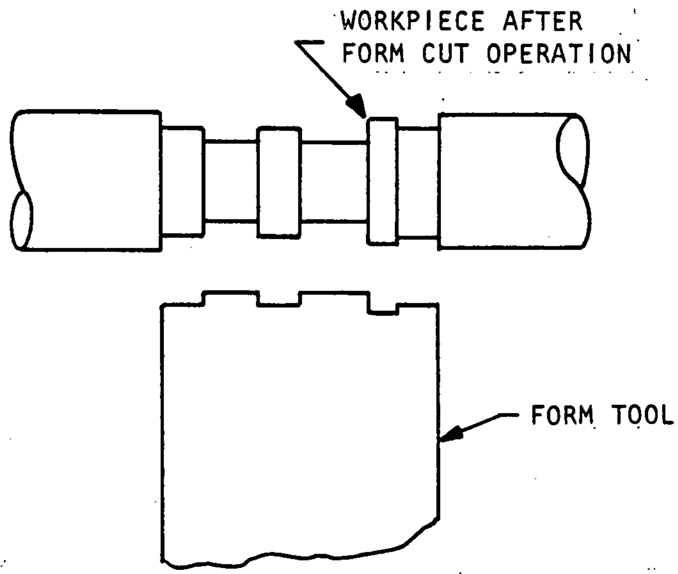


Figure 2. Form Tool for Turned Parts

This is a direct result of the low feeds required when using tools having near zero nose radii and the need for keeping sharp cutting tools.

Chamfering holes before tapping often eliminates the mound of material the tap produces at hole entrance and exit.

Heavy cut-off burrs such as the one shown in the left hand portion of Figure 3 can be prevented by using a vise which holds the workpiece as well as the bar stock until the cut is completed. Theoretically, supporting the workpiece with a piece of backup material should prevent burrs. From a practical standpoint however backup material only helps to minimize burrs.

This can be seen by looking closely at a workpiece. Most operations produce burrs at more than one location. In drilling for example one obtains a burr at both hole entrance and hole exit. In a milling operation burrs can be produced on up to ten edges. Thus at best one minimizes only burrs on one side of the workpiece. While minimizing burr size is a distinct advantage, it is not as desirable as burr prevention.

Theoretically it would be possible to completely cover a part with "backup" material and prevent all burrs. From a practical standpoint this is not very realistic because the "backup" material must have the same properties as the workpiece to prevent burr formation.

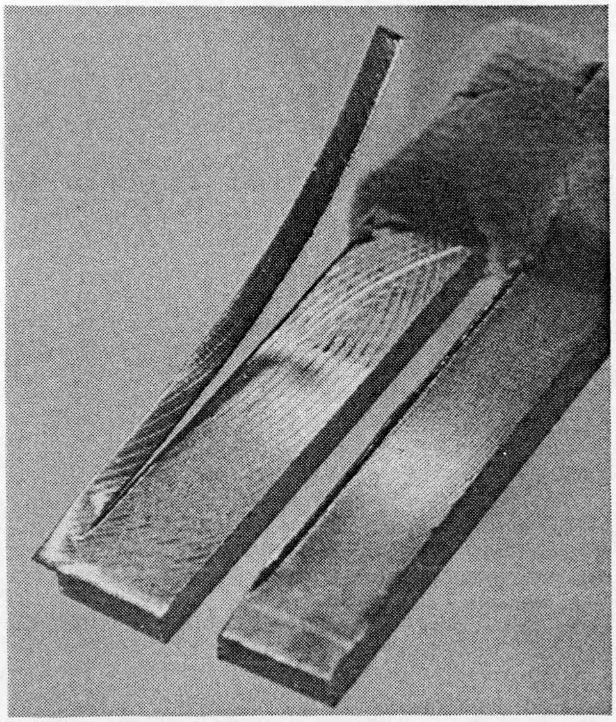


Figure 3. Examples of Cut-Off Burrs

BURR MINIMIZATION

Since the prevention of burrs is not an economically realistic approach for most companies or most products, it is essential to consider how burr size can be minimized. In using this approach to minimizing deburring costs it is convenient to consider burr minimization from two viewpoints:

- Physically limiting burr size and toughness; and
- Making the burr easy to remove.

Controlling Burr Size

It is almost trivial to point out that small burrs are easier to remove than large burrs, and yet few individuals have made any attempt to analytically determine what maximum burr size should be allowed for their machining and deburring conditions. For small parts having tolerances of ±0.002 inch (±50.8 μm) burrs 0.003 inch (76.2 μm) thick by a similar height can be readily removed by loose abrasive processes. For very miniature parts having tolerances of ±0.0002 inch (±5.08 μm) burr size must be maintained at 0.001 inch (25.4 μm) thick or thinner. For different processes and geometries different limits exist.

Burr minimization requires a quantitative knowledge of how burrs vary with machining variables. Minimum cost deburring also requires a knowledge of how deburring costs vary with burr properties. Lesson 3 summarizes the existing knowledge of how machining variables affect burr size, no data have yet been published on deburring costs as a function of burr size.

Several general rules about burr minimization are known:

- Sharp tools minimize all burr properties;
- Workhardening materials produce thicker burrs than nonworkhardening materials;
- Burr hardness is higher than the parent material hardness for workhardening material;
- Supporting the machined edges minimizes burr size;
- Ductile materials form larger burrs than brittle materials; and
- High feed rates typically (but not always) produce thick burrs.

Table 2 illustrates the differences in burr properties produced by sharp and dull cutters. If a choice is available in materials, choose a non-workhardening material to minimize burr thickness and the hardness differential between the burr and workpiece. While the last rule in the above list is universally known the actual economics of this approach are often ignored. Several companies have found that "burr" type cutters greatly reduce the burr thickness and length produced in milling operations.

It is significant to note that hole saws will typically produce a smaller burr than twist drills in ductile material. This is in part because they greatly reduce the cutting forces which create the burrs.

The blanking industry now uses an acoustical die monitor to detect abnormal burrs and to prevent their occurrence.

<u>Burr Placement</u>

As indicated previously, burr minimization in its broadest interpretation includes more than just minimizing burr size. It involves more than a knowledge of how all variables affect a given operation. It includes other approaches to making the burr easy to handle.

Table 2. Comparative Burr Sizes Generated by Milling Operations

Material	Condition	Burr Thickness (inch)*	Burr Height (inch)	Hardness Parent Material	Knoop Burr
Aluminum	Abusive Face Milling	$\bar{\chi}$0.0078 σ0.0011	0.0138 0.0045	115 4	129 9
	Gentle Profile Milling	$\bar{\chi}$0.0023 σ0.0003	0.0015		
Low Carbon Steel	Abusive Face Milling	$\bar{\chi}$0.0046 σ0.0010	0.0255 0.0191	230 7	275 17
	Gentle Profile Milling	$\bar{\chi}$0.0014 σ0.0002	0.0024 0.0009		
Stainless Steel 303Se	Abusive Face Milling	$\bar{\chi}$0.0049 σ0.0020	0.0095 0.0053	305 0	428 56
	Gentle Profile Milling	$\bar{\chi}$0.0020	0.0013		
Beryllium Copper	Abusive Face Milling	$\bar{\chi}$0.0045 σ0.0008	0.0189 0.0017	249 7	268 22
	Gentle Profile Milling	$\bar{\chi}$0.0007 σ0.0005	0.0016 0.0011		

Abusive Face Milling--Dull cutter and 0.025 inch depth of cut.

Gentle Profile Milling--Burr produced by the bottom of a 1/4 inch diameter end mill 2730 RPM, 9-3/16 IPM.

Knoop Hardness Number with 100 Gram Load (249 = Rc 24; 115 = RB 73)

$\bar{\chi}$ = average measurement.

σ = standard deviation of measurements.

* 0.001 inch = 25.4 μm.

Making the burr easy to remove involves two aspects:

- Locating the burr in the best position; and
- Controlling burr size by appropriate selection of machining sequences.

Figure 4 provides an excellent example of burr placement. The cut-off burr in the right hand view is masked by the large diameter of the part. In the left hand view the burr is exposed to the action of vibratory deburring and can be readily removed provided tolerances are adequate. Figure 5 is another example of burr placement. Production routing sheets should indicate where the cutter exit burr should be. In this case a burr at the step in diameter would double the time required to deburr this part.

Correct burr placement can pay big dividends on milled parts because of the large number of edges produced. On intersecting features placing the burr on the most accessible edge can reduce burr costs by 50 percent. The correct placement of burrs can change a normally hand deburr situation to a much more economical and repeatable vibratory deburr operation. In some operations burr placement can be controlled by a simple N/C tape change. In some cases climb milling rather than conventional milling will provide better location. Since tooling may be involved it is important to consider burr placement in the preliminary processing steps.

When a rollover burr forms near a hub such as shown in the upper left view of Figure 6, extra care must be exercised to prevent scratching the hub if the burr is removed by hand. If the rollover burr is located at the opposite end of the part, no projection will interfere with the deburring. The same is true of the burr shown in the right hand view. For the easiest and cheapest burr removal, the burr must be carefully positioned.

Locating the burr cannot be an afterthought. If a redirection of cutting forces is required, existing tooling may have to be altered to resist the forces. Deburring requirements must be visualized <u>before</u> the machining process and tooling are finalized.

Figure 7 is another excellent example of the effect of burr location. If the hobbing exit burr is allowed to form on the hub side, precision deburring will be very time consuming. By fixturing the part so the hob exits over the flat face, the hobbing burrs can be removed easily by a quick hand sanding operation. The small sanding burrs can then be removed by brushing or in one of the loose abrasive processes.

VIBRATORY DEBURRING CAN BE EXPEDITED IF CUTOFF BURR IS LEFT ON ROUNDED END OF SCREW MACHINE PART RATHER THAN ON FLAT END

Figure 4. Place the Burr for Easiest Removal

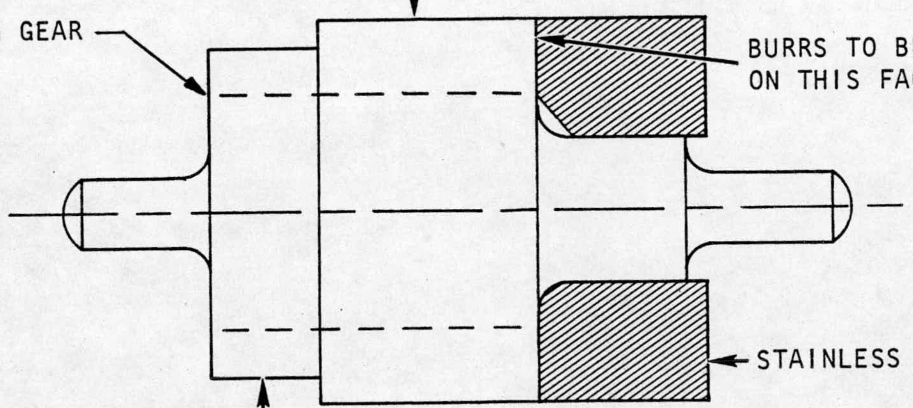


Figure 5. Identify Desired Burr Location and Use Backup Materials to Minimize Burrs

Even when back-up material is used in multiple part hobbing (Figure 8) the cutter should exit from the flat surface. Since direction of feed or rotation cannot be changed on ratchet teeth and non-gear shapes, burr location must be chosen before hobs are ordered.

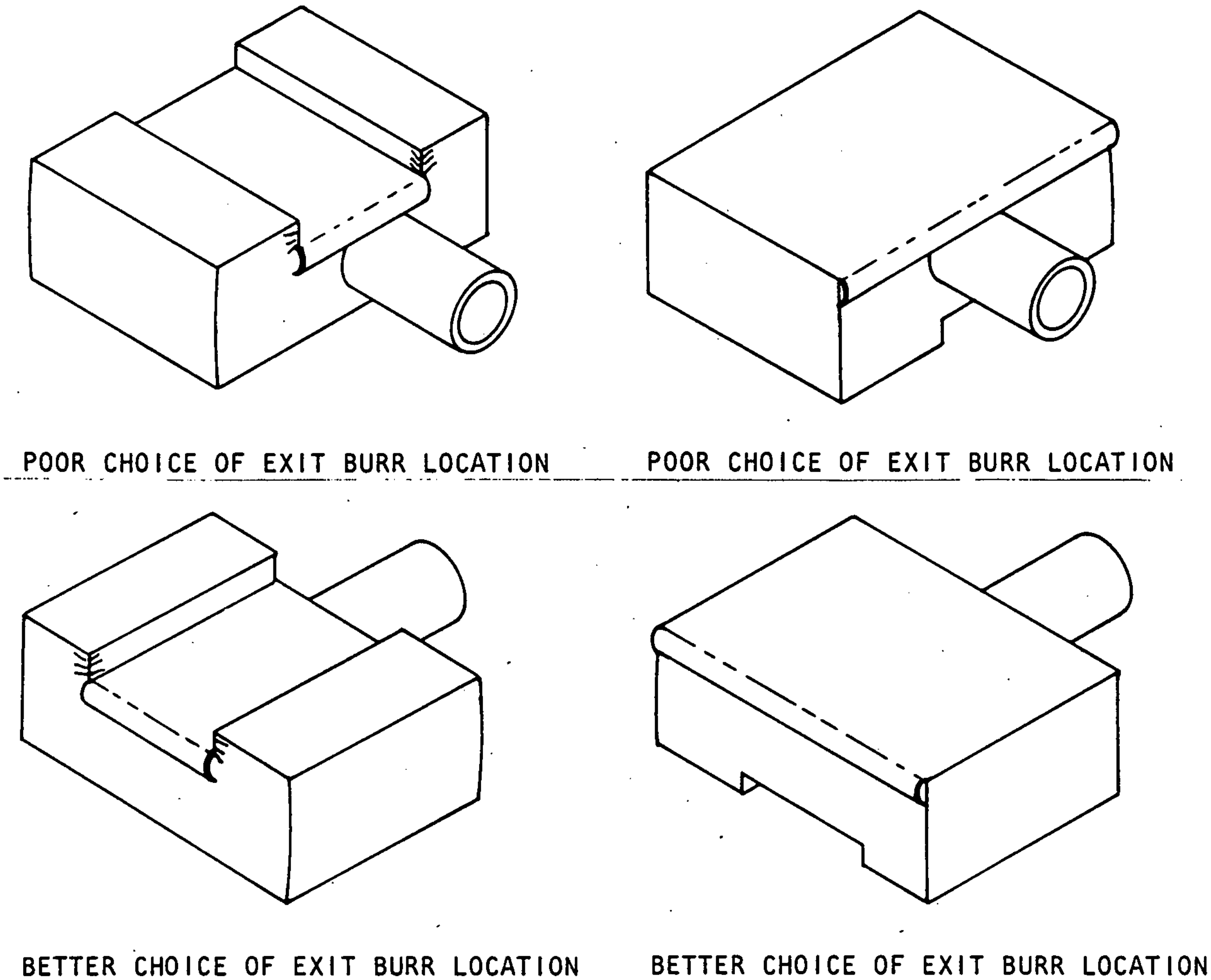
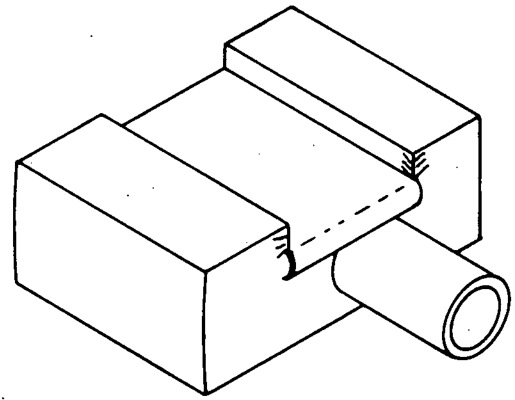


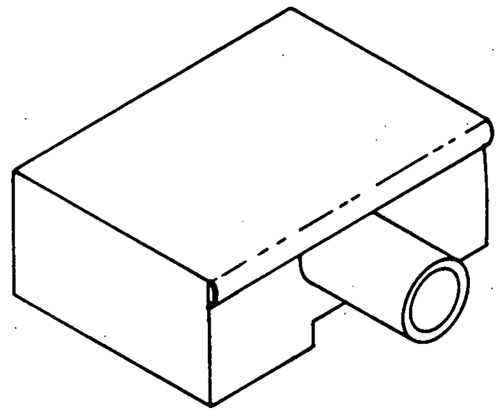
Figure 6. Burr Locations

When milling "L-shaped" configurations (Figure 2 in Lesson 1), exit burrs should be placed on the back and top rather than under ledges.

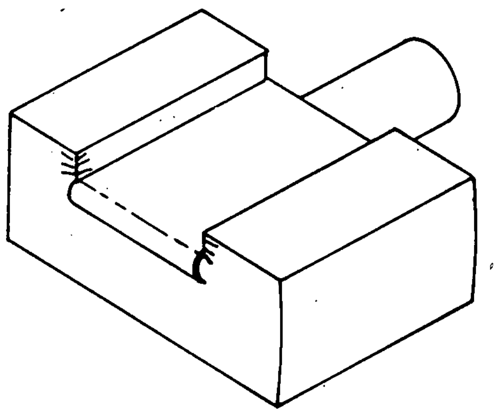
The decision of which machining sequence to use can affect deburring time. As an example the part in Figure 9 would typically be turned then the three flats would be milled. This creates two undesirable facets though. First milling typically makes a heavy burr, and secondly deburring would require a separate operation. The company which produced this part chose to mill the flats before turning the stem diameter. This produced a smaller burr and allowed the operator to brush the burrs off with a wire brush as a part of the lathe operation.



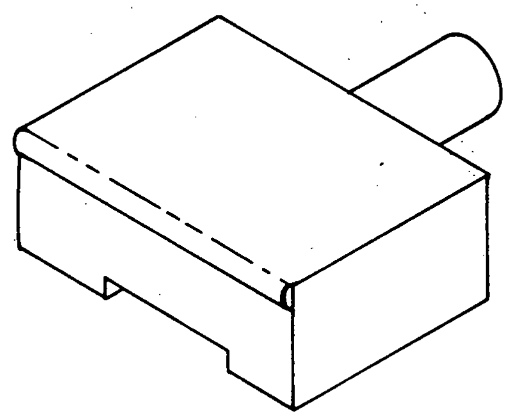
POOR CHOICE OF EXIT BURR LOCATION



POOR CHOICE OF EXIT BURR LOCATION



BETTER CHOICE OF EXIT BURR LOCATION



BETTER CHOICE OF EXIT BURR LOCATION

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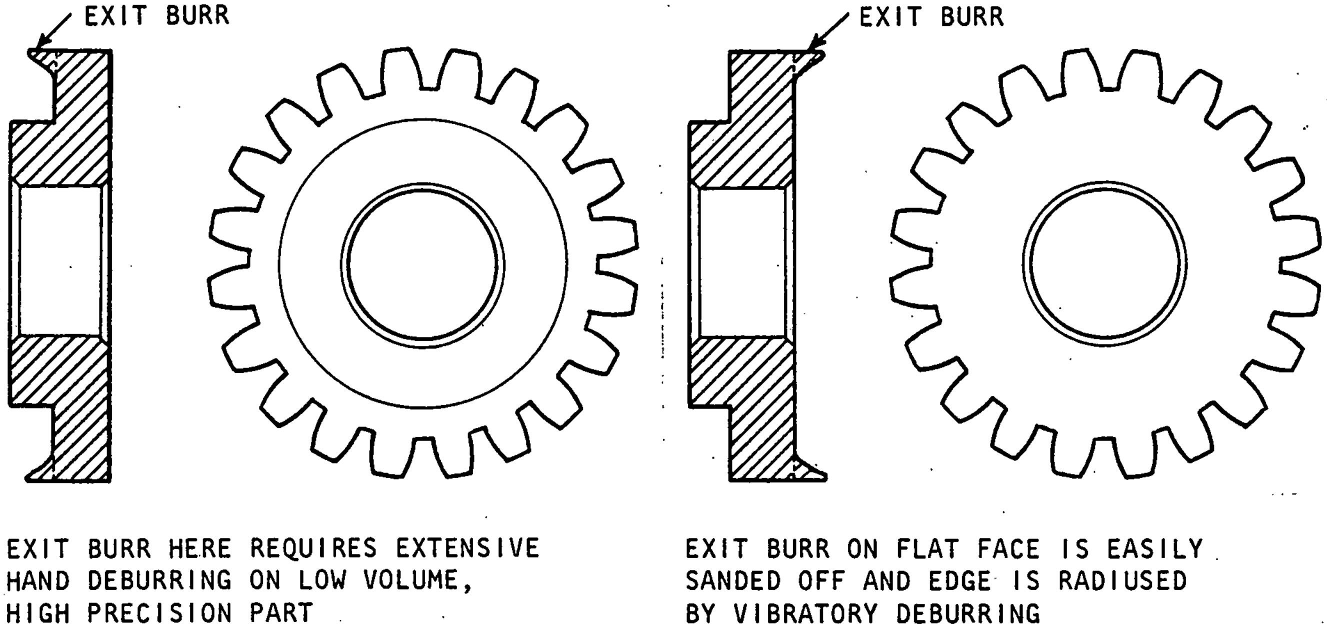


Figure 7. Effect of Burr Location

When the manufacturing engineer considers the machining sequence he wants to follow he should consider the "burr" as significant a factor as the desired surface finish and tolerance. The following checklist has been prepared to help in processing and in troubleshooting burrs:

ASK YOURSELF

1. Does the burr have to be removed?

2. Can the part be redesigned?

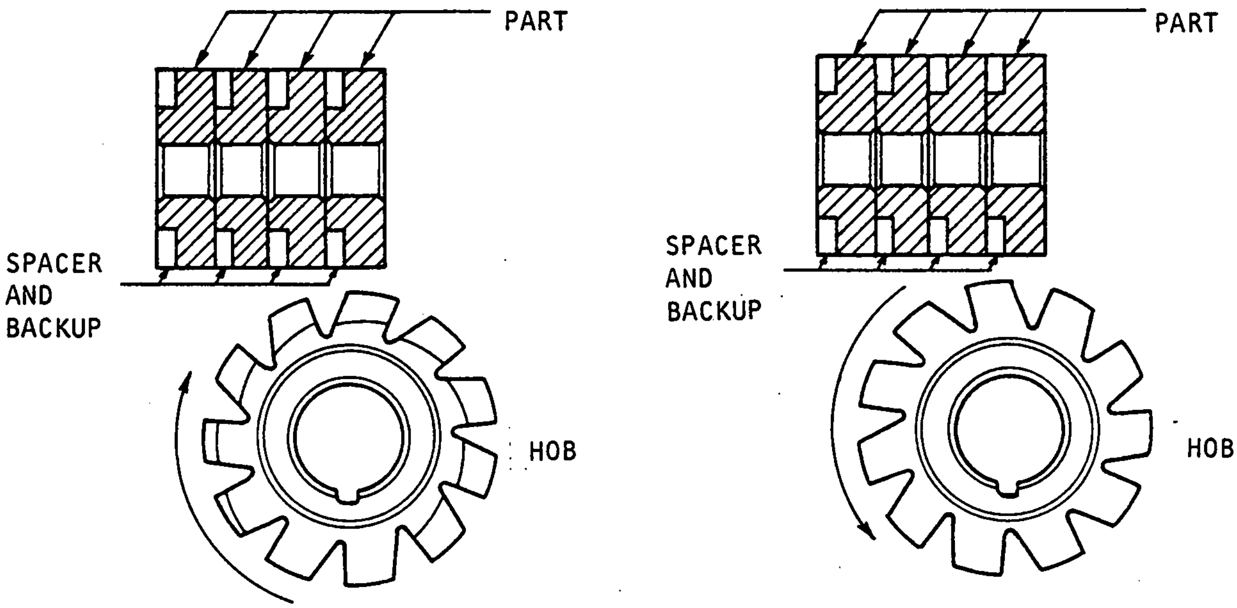
   a. for less machining?
   b. for less deburring?

3. Will the burr be cut off in a later machining operation? If the machining sequence were changed, would the burr be cut off?

4. Is the burr accessible?

   a. Should I change the sequence of operation?
   b. Should I change the direction of the cut?

5. Can I choose a cutter that gives a smaller burr?



PREFERRED APPROACH: THIS PUTS LARGE BURR ON FLAT FACE OF LAST PART.

POOR APPROACH: THIS THEORETICALLY ELIMINATES LARGE EXIT BURR SINCE CUTTER CUTS AGAINST BACKUP. FROM A PRACTICAL STANDPOINT, THIS OFTEN DOES NOT OCCUR BECAUSE OF VARIATIONS IN SPACER AND WORKPIECE THICKNESS AND FLATNESS WHICH ALLOW GAPS BETWEEN BACKUP AND WORKPIECE SOFT SPACERS WILL ALLOW BURR TO FORM EVEN IF GAPS DO NOT EXIST.

Figure 8. Preferred Versus Poor Approaches to Hobbing

6. Do I know the feed rate which gives the smallest burr?

7. Can I use a subsequent heat treat to make the burr brittle?

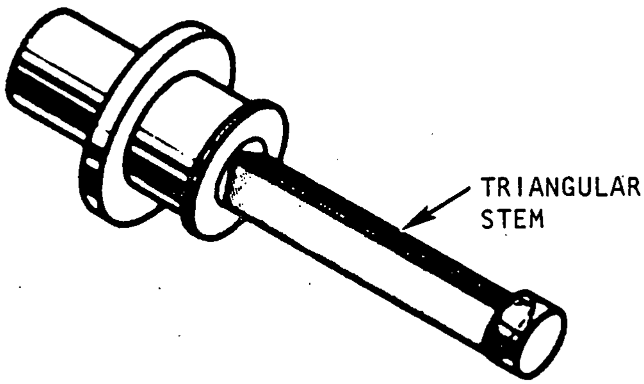
8. Would a change in coolant or method of application make the burr brittle?

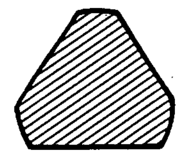
9. Does the burr have to be removed <u>now</u>?

SPECIFIC EXAMPLES OF MINIMIZATION APPROACHES

<u>Minimizing Burrs by Reducing Forces</u>

As a general rule any factor which minimizes cutting forces will minimize burrs. Reducing the axial and radial depths of cut will





CROSS SECTION

TURN STEM AFTER MILLING FLATS
WIRE BRUSH ON LATHE TO REMOVE BURRS

Figure 9. Effect of Process on Deburring

reduce forces. In this case; however, the axial depth of cut (when axial is defined along the tool axis) does not influence burr size (see Lesson 2). The material properties influence forces, as do coolants, tool sharpness, tool material, tool design, and tool surface finish. Special techniques such as intentionally induced high frequency vibrations and electrical currents passing between the tool and the workpiece also will reduce cutting forces. These in turn will reduce the size of burrs generated.

Reducing the Size of Burrs Produced in Drilling

Burrs form on both the entrance and exit sides of drilled holes. The burrs on the entrance side are typically small while those on the exit are typically very long and ragged. Entrance burrs typically have a triangular cross section while exit burrs are basically rectangular.

As seen in Table 3, increasing feedrate increases exit burr properties. Increasing the helix angle reduces all burr properties. The most significant changes to exit burr properties can be made by using high helix drills (37.5°). Reducing feedrate 60 percent can reduce burr height by 40 percent. Since exit burr height can be equal to the drill radius, drill diameter can be a major factor in burr size. Reducing spindle speed from 750 to 375 rpm reduced burr thickness less than 12.7 µm (0.0005 inch). The relative importance of each variable in Table 3 is indicated by its ranking in the 'Significance' column.

Table 3. Effect of Drilling Variables on Burr Size in 303 Se Stainless Steel

Variable	Entrance Burr Thickness	Entrance Burr Height	Exit Burr Thickness	Exit Burr Height	Significance Ranking
Helix Angle	--	--	--	--	1
Feedrate	0	0	+	+	2
Diameter	0	--	+	+	3
Surface Velocity	+	--	+	x	4
Corner Angles*	x	x	--	+	5

-- = Increasing variable reduces burr property
0 = No effect
\+ = Increasing variable increases burr size
x = Conditions not studied
*For conventional drills, the corner angle equals 180! minus half the point angle.

Exit burr height, b_L, the factor most influenced by feedrate, can be approximated by equation 1 for 0.125 inch (3.175 mm) diameter drills, at feedrates of 0.0015 inch/rev (38.1 μm) or less.

$$b_L = c_1 f + c_2 \tag{1}$$

where:

b_L = burr height;

f = feedrate;

c_1 = constant; and

c_2 = constant.

And the constants shown in Table 4 are used.

Exit burr thickness, b_t, can be expressed by Equation 2.

$$b_t = c_1 f + c_2 \tag{2}$$

Table 4. Constants for Use With Equation 1

Materials and Hardness	Metric Units (μm) c_1	Metric Units (μm) c_2	English Units (inch) c_1	English Units (inch) c_2
303 Se Stainless Steel (R_c 29)	13.33	559	13.33	0.022
17-4 Ph Stainless Steel (R_c 42)	6.67	432	6.67	0.017
1018 Steel (R_B 99)	4.00	406	4.00	0.016
6061-T6 Aluminum (R_B 54)	6.00	254	6.00	0.010

When feedrate is given in μm/rev and the metric constants are used, burr length will be in μm. When feedrate is given in inch/rev, the English constants should be used to give burr length in inches.

when the constants shown in Table 5 are used and b_t is in inches. Other tests on AISI 1018 steel (BHN 150) reveal the following relationship between drilling parameters. This basic relationship is probably representative of that to be found for many materials. The exponents; however, would vary for different materials.

$$b_t = 4.271\, H^{-1.72} P^{0.84} L^{0.36} f^{0.86} \qquad (3)$$

Where:

H is the helix angle (degrees);

P is the point angle (degrees);

L is the lip clearance angle (degrees); and

b_t is the burr thickness (inch).

A preliminary examination of Equation 3 shows that increasing the helix angle and lip clearance angle decreases the burr thickness. The equation is least affected by the lip clearance angle. Decreasing the point angle and feed also decreases the thickness.

Table 5. Constants for Use With Equation 2

Drill	Metric Units (μm)	English Units (inch)
Four Facet		
c_1	1.0	1.0
c_2	0.33	0.0013
Eight Facet		
c_1	1.0	1.0
c_2	30	0.0012
Radial Lip		
c_1	1.0	1.0
c_2	25	0.0010

When feedrate is given in μm/rev, the metric constants should be used to give the burr thickness in μm. When feedrates are given in inch/rev and the English constants are used, burr thickness will be in inches.

If drills have a lip clearance angle of 9.2° , Equation 3 can be represented by Figure 10. From this figure it can be seen that there are numerous helix angle, point angle and feed combinations which produce the same burr thickness. The equation and graph also show that significant reductions in burr thickness are possible by correct selection of the helix angle, point angle and feed. Figure 10 and Equation 3 show that a 0.0043 inch (109.2 μm) burr thickness could be expected when drilling with a 27° helix angle, 112° point angle, and 0.006 ipr (152.4 μm/rev) feed. By increasing the helix angle from 27 to 36°, which can be achieved by purchasing commercially available high helix drills the burr thickness is reduced to 0.0026 inch (66.0 μm). If the feed is lowered from 0.006 to 0.0035 ipr (152.4 to 88.9 μm/Rev) and the point angle reduced from 112 to 98°, the burr thickness becomes

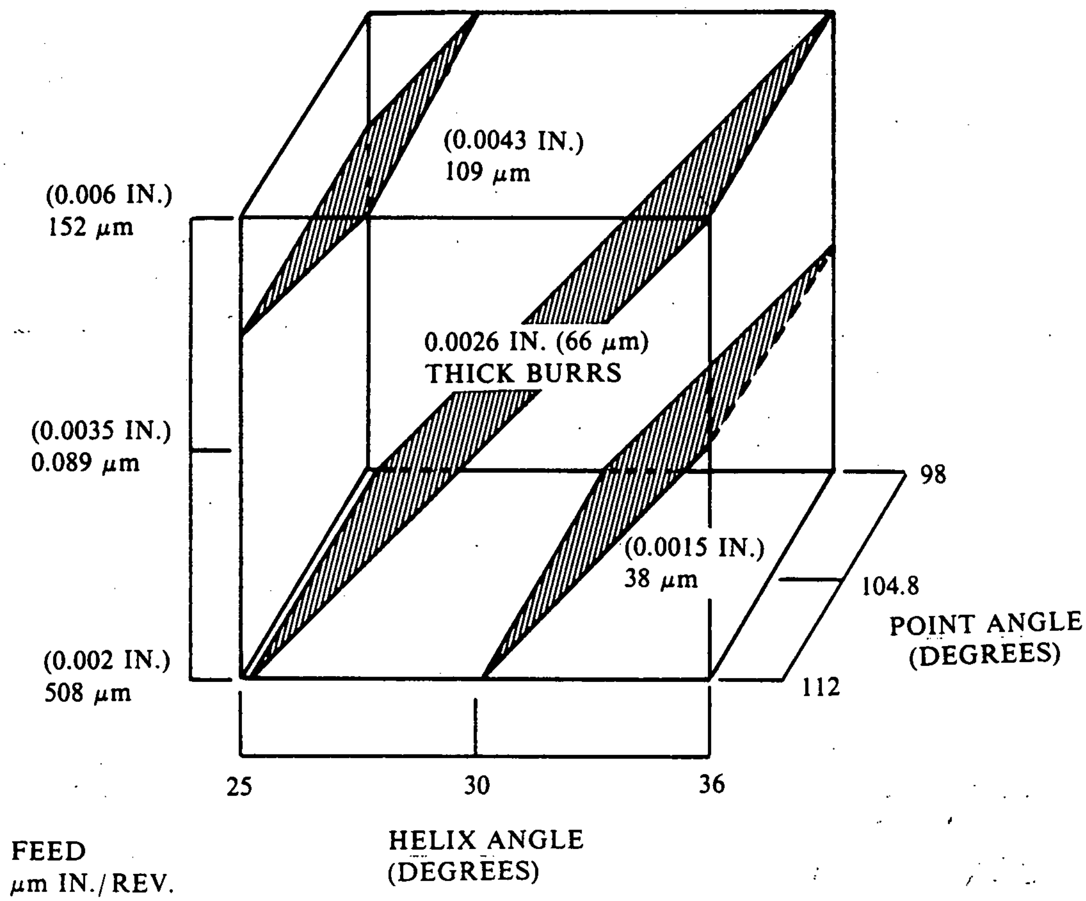


Figure 10. Burr Thickness Response Surfaces

0.0015 inch (38.1 μm). A burr with this thickness may be removed by less costly deburring methods such as barrel tumbling or vibratory deburring.

For a conventional drill, drilling AISI 1018, 150 BHN steel, the burr thickness can be reduced by increasing the helix angle, reducing the point angle or lowering the feed. Only slight reductions in burr geometry are possible by increasing the lip clearance angle. Figure 10 along with Equation 3 may be used as design tools by the manufacturing engineer. This information allows him to investigate various drill geometry and feed combinations with respect to burr thickness. No special grinding equipment is required to alter the helix angle since drills with high helix angles are commercially available. Point angles may be varied on shop drill grinding equipment. Feed can be changed by either programming the machine tool for lower breakthrough feeds or reducing the nominal feed to a lower level.

Using the same material the effects of spindle speed, and workpiece hardness can be expressed as,

$$b_t = 234.6\ N^{0.783} B^{0.998}. \qquad (4)$$

Where:

N is spindle speed (rpm); and

B is the Brinell Hardness Number of the workpiece.

A preliminary examination of Equation 4 shows that increasing the spindle speed or material hardness reduces the thickness of an exit burr.

The practical aspects of the results shown in Figure 11 are that for a given workpiece hardness the burr thickness can be reduced by increasing the spindle speed. It can be seen that for a workpiece of BHN 125 hardness the thickness can be reduced from 0.010 to 0.007 inch (25.4 to 177.8 μm) by increasing the spindle speed from 800 to 1300 rev/min. Also revealed is that changes of 25 hardness points cause variations of 0.001 to 0.002 inch (25.4 to 50.8 μm) for the higher and lower Brinell numbers respectively.

An explanation on why the thickness is reduced with increasing hardness is based on the materials resistance to plastic flow. Physically, the material which remains to form into a burr at drill break-out is less. This is caused by the harder material resisting "push-out," thus allowing more material to be cut with less available to be plastically deformed into a burr. Essentially the harder material acts as a back-up material.

The effect of spindle speed is more complex and may be related to the dynamic properties of the material. Higher strain rates tend to increase the shear strength of many steels, thus they would react as a higher hardness material might.

The use of a hard backup (R_c 42) minimizes exit burr size (Figure 12), as does the use of a small clearance hole in the bottom of the fixture holding the part. If the fixture hole is within 0.001 inch (25.4 μm) of the drill diameter and on the same centerline, the burr size will be 0.0005 inch (12.7 μm) or smaller. On precision miniature holes, a clearance hole diameter 0.002 inch (50.8 μm) larger than the drilled hole will only slightly improve burr properties above those of a large clearance hole. In some cases reaming after drilling will reduce burr size. Where drills must produce 150 to 1000 holes each, the radial lip drill point can result in shorter and thinner burrs, but this is often not true in short run applications. In materials such as aluminum, the use of correct coolants can also noticeably reduce burr size.

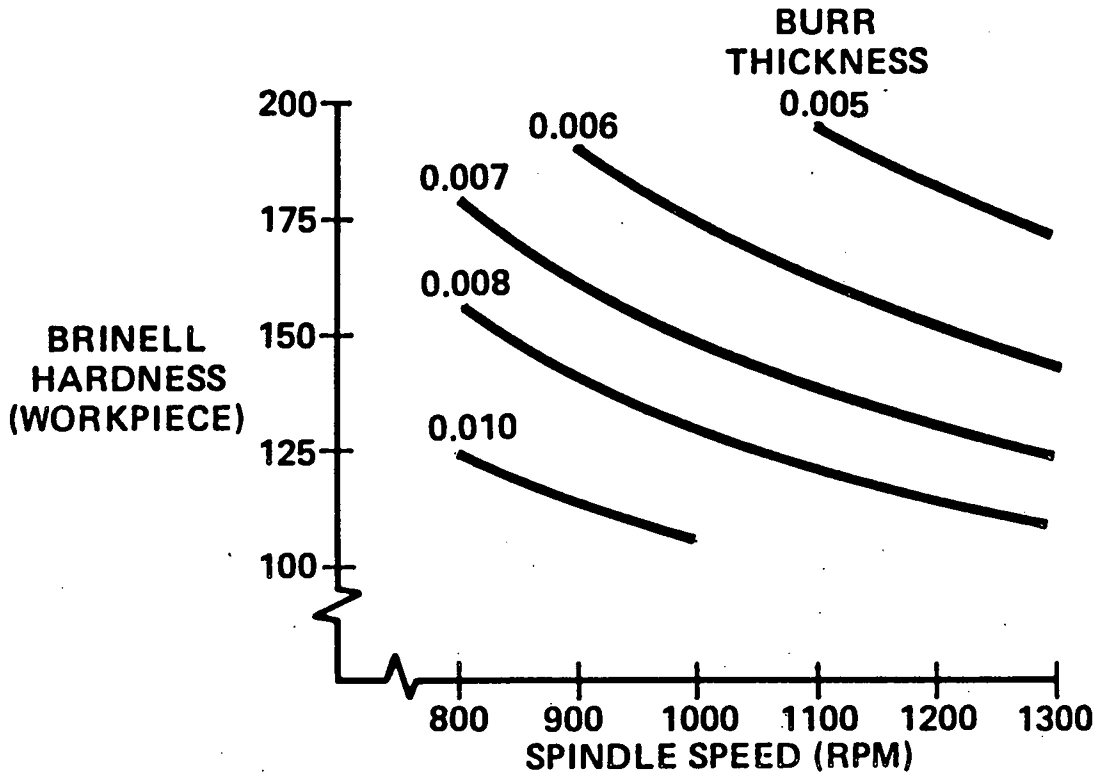


Figure 11. Effect of Spindle Speed and Hardness on Burr Thickness

With the exception of exit burrs in stainless steel, no relationship has been documented between burr thickness and height. In stainless steel, high burrs also indicated the existence of thick burrs. The minimization of feedrate surges as the drill breaks through the bottom side of the workpiece will help reduce exit burr size.

Minimizing Burrs Formed by Blanking Operations

In blanking or piercing operations, burrs are produced only on the bottom of the workpiece.

Published data indicates that a large die radius reduces burr size in conventional blanking. Burr thickness and height also increase as punch-to-die clearance increases, but the relationship is not linear. For steels, clearance of 2.5 percent of the stock thickness generally produces the smallest burr but such tight fits greatly increase tool wear. Initial burr size is reduced as the punch face finish is improved. Burr size is also influenced greatly by the construction of the die button. In conventional

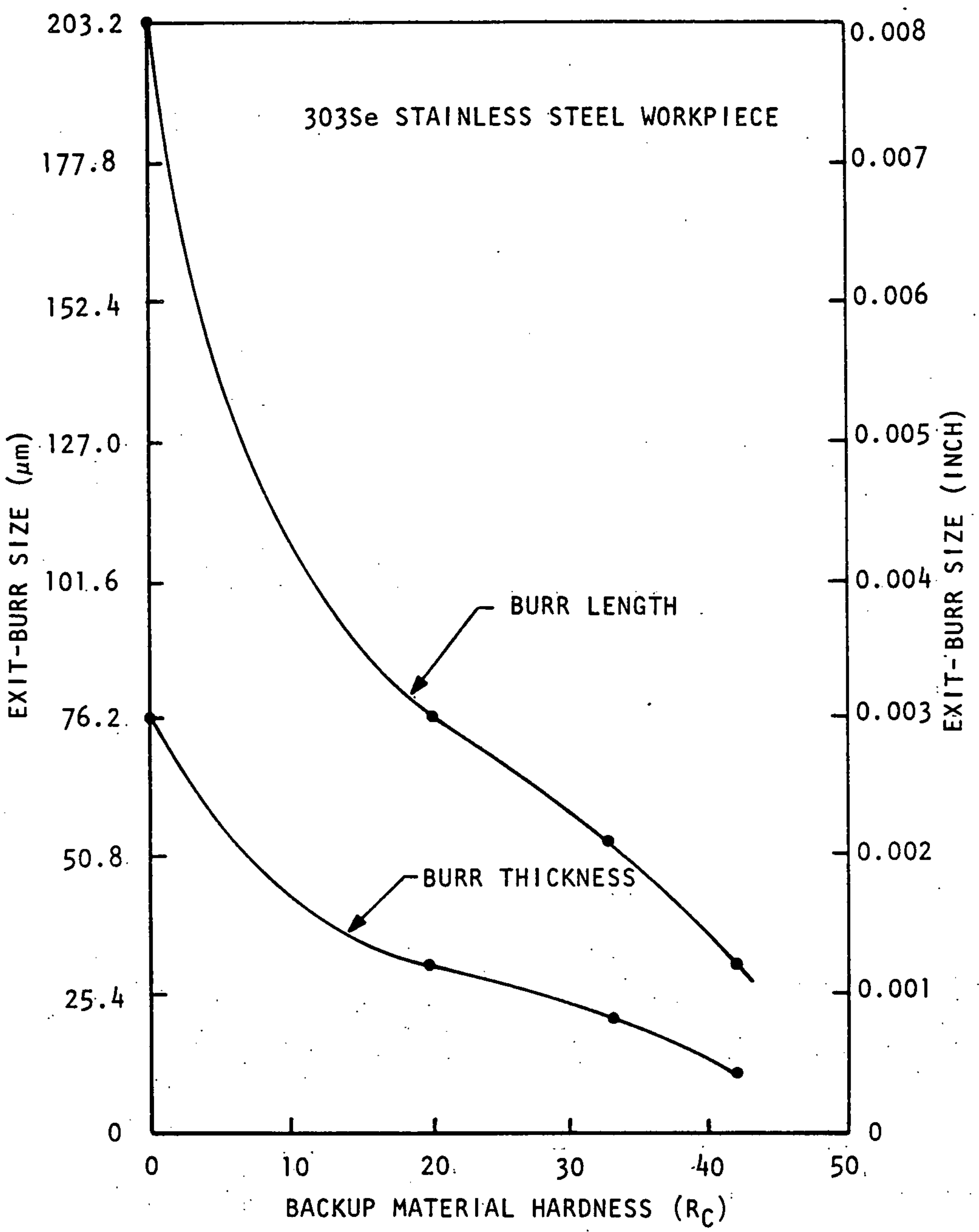


Figure 12. Effect of Backup Material Hardness on Burr Size

dies, burr height generally will increase at a rate of 0.002 inch (50.8 μm) per 100,000 strokes or faster, depending upon die construction and materials.

Minimizing Burrs From Turning

Feedrate, depth of cut, side cutting edge angle (SCEA) and back rake are the factors which most influence burr size in turning. Figures 13 and 14 illustrate typical effects of depth of cut and SCEA. As seen there, a large positive SCEA can reduce burr thickness by two-thirds. Reducing depth of cut will also reduce burr properties. For a 45° SCEA a reduction from 0.120 to 0.040 inch (3 to 1 mm) depth of cut reduced burr thickness by 50 percent. Reducing feedrate by 75 percent typically will reduce burr thickness by 50 percent. In some instances increasing the nose radius will reduce both burr height and thickness.

The Effect of Workpiece Material Properties on Burr Size

Two material factors are directly linked to burr size:

- Workpiece ductility; and
- Strain hardening exponent.

Large burrs cannot form in brittle materials. Cast irons, for example, often have edges with no visible burr. These materials have values of elongation of 0.5 to 3.0 percent in a 2 inch (50 mm) gage length. Since the material has little capacity for plastic deformation, large burrs cannot form. If, however, the cutting tool heats the cast iron enough to change its structure, and the material is no longer brittle at the edges or machined surfaces, a noticeable burr can form. Tungsten is another example of a basically nonductile material.

As explained in Lesson 3, the strain hardening exponent n is the second factor which influences burr size. As n increases, burr thickness typically increases, although the relationship is not usually directly proportional.

These two material properties can be used to predict the tendency for a material to form large or small burrs. A brittle material which is not sensitive to cutting heat will produce short burrs; thus elongations of 5 percent or less imply the existence of short burrs, while elongations of 60 percent, such as occur with 303 Se stainless steel, signal the likelihood of tall burrs. Since burrs form by different mechanisms, most but not all burrs will be shorter or smaller than those in a less ductile material.

Values of n of 0.1 indicate a material will form a burr of normal thickness. An n of 0.5, such as associated with 303 Se stainless steel, indicates that thick burrs probably will occur.

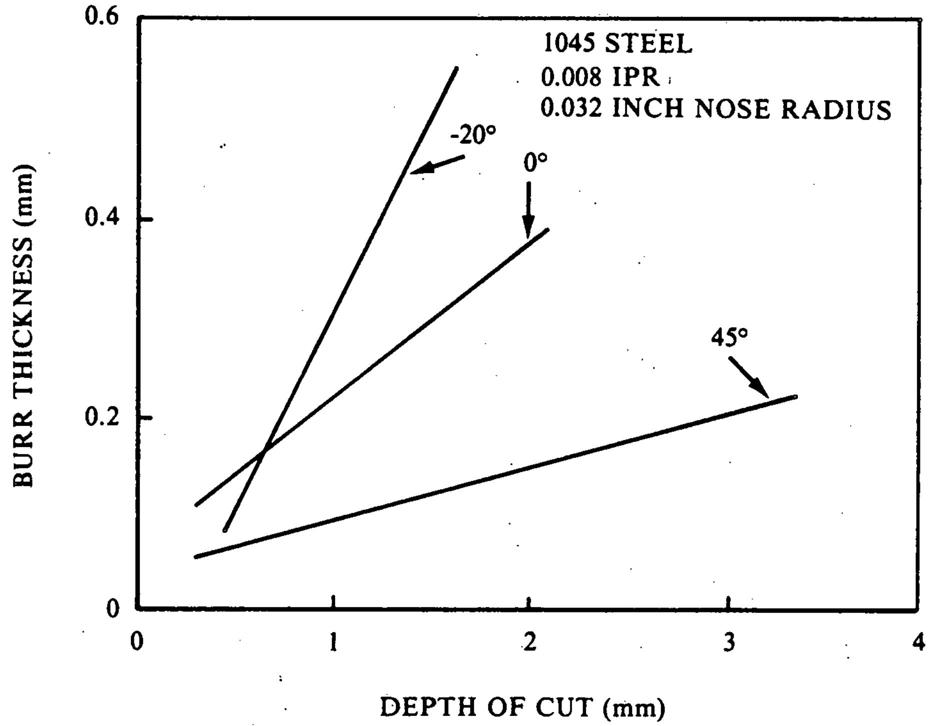


Figure 13. Effect of SCEA and Depth of Cut on Burr Height

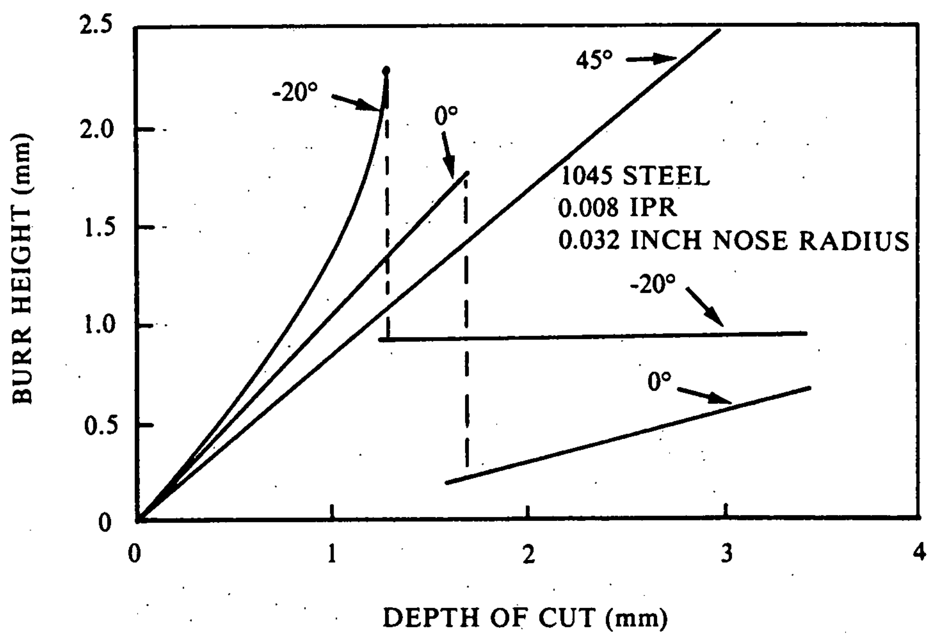


Figure 14. Effect of SCEA and Depth of Cut on Burr Thickness

Table 6 lists some common values of n and elongation. Values for other materials can be found in references 1, 2, and 3.

Effects of cutting parameters on burr size are known for several processes. Studies have been performed on reaming, grinding, ballizing, end milling, side and face milling. More extensive data are available on the processes just discussed.

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BDX-613-2373

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SPECIAL PROJECTS: Deburring

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