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THE MEASUREMENT OF BURRS

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Burrs
Deburring
Milling
Drilling
Blanking
Turning
Grinding
Broaching
EDM

THE MEASUREMENT OF BURRS

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ABSTRACT

The properties of machining and blanking burrs are indicators of metal cutting efficiency and deburring costs. When burrs are used as a criteria for monitoring tool wear or determining optimum tool geometry a repeatable burr property must be chosen. The techniques required to obtain repeatable burr lengths, thicknesses, and hardnesses are discussed.

THE MEASUREMENT OF BURRS

INTRODUCTION

What makes a burr difficult to remove? How can we minimize burrs? What is the relationship between burr size and deburring costs? What tool geometry minimizes burrs? How big a burr will vibratory deburring remove? These questions are the basis for several current studies by leading companies. The key to answering each of these questions rests in the ability of the researcher to define and measure the appropriate burr properties.

The measurement and observation of burrs is of interest for at least two reasons. The principle reason of course is that burr removal is a multi-billion dollar yearly expenditure for industry. If burrs could be prevented or minimized, removal costs could be greatly reduced. Secondly, the formation and size of burrs are indicators of metal cutting efficiency. As such the observation of burr properties can provide both academic and practical indicators of metal cutting mechanics. Although measurements of burrs can serve a number of useful purposes, they can also produce misleading information. A poor choice of burr properties to be measured will indicate that those burr properties are not repeatable, and hence not useful for any analysis. However, if a more realistic statistic had been chosen a definite and repeatable relationship could have been established. The following paragraphs describe some of the considerations which must be made when measuring burrs.

In the past, measuring burrs meant measuring burr length (height). Today this approach to defining burrs is not adequate to answer the questions being asked. It is not sufficient because burr length alone is only meaningful when it is associated with a specific material and a specific set of machining conditions. It cannot serve as a universal criteria to answer the above questions.

THE FOUNDATIONS OF BURR MEASUREMENT

There are four basic foundations to build on when measuring burrs.

- Burr properties depend on which of four metal cutting mechanisms produced the burr

- Burr length is not the sole property; thickness, shape, and toughness are equally as significant
- The ability to obtain repeatable burr measurements depends on the definition of each property
- Repeatable results can only be assured by measuring several samples

BURR FORMATION

The measurement of burr properties requires at least a rudimentary knowledge of how the burr formed. Without this knowledge it is easy to make several erroneous assumptions that will invalidate or at least limit the usefulness of a complete study. Since the formation of burrs has been described in some depth elsewhere [1] only the basic mechanisms of burr formation need to be pointed out here. The four basic mechanisms involved are:

- 1) Lateral extrusion of material (Poisson burr)
- 2) Bending of chip (roll-over burr)
- 3) Tearing of chip from workpiece (tear burr)
- 4) Incomplete cutoff (cutoff burr)

BURR PROPERTIES

What makes a burr difficult to remove? The answer varies with each situation but the following list is typical.

- Burr Thickness*
- Burr Location
- Burr Toughness
- Burr Length
- Workpiece Tolerances

For most applications the above list is in approximately the correct order of significance. It is burr thickness not burr length which makes a burr most difficult to remove. This is easy to see by looking at two extremes. Grind a piece of 303 Se stainless steel, then take a dull end mill and cut a channel in the same workpiece. Compare the burrs. At 0.001 inch per pass, a 0.010 inch downfeed will produce a 0.007 inch long by 0.0002 inch thick grinding burr on one edge. One of the milling burrs will be 0.003 inch thick and 0.005 inch long. Experience tells us that the grinding burr can be readily removed with a finger nail. The milling burr requires considerable effort to remove, yet it is shorter. A similar comparison can be drawn between hardness and length.

*Thickness as used in this paper indicates thickness at the base of the burr, i.e., the juncture of the burr and the parent material.

For a specific machining operation is burr length directly relatable to burr thickness? From a theoretical standpoint the answer is yes, but from a practical standpoint, the relationship is not readily evident. Nowhere in the literature has an empirical relationship yet been described. A few authors maintain that burr lengths will be roughly 20 times burr thickness. While for one material, one machining operation and one point in tool life this may be true, it is by no means universally true. Although studies are currently underway to determine such relationships between burr length and thickness, it will be several years before sufficient data is available to establish a universal relationship. As a result it behooves burr researchers to measure all the burr properties which are meaningful.

Burrs assume many shapes. As shown in Table 1 they can be triangular, rectangular, or spherical in cross section, and they can be uniform*, ragged (irregular), or feather-like in length. Each of these shapes indicate a different metal cutting phenomena and as such the shape should be documented in any study.

TABLE 1

Typical Burr Geometries

<u>Operation</u>	<u>Typical Burr Shape</u>
Blanking	- Triangular cross section
Fine Edge Blanking	- Thin rectangular cross section
Milling	- Rectangular or triangular, cross section and feathery, uniform or ragged length
Drilling	-- Triangular or rectangular cross section, uniform or ragged length
Turning	- Rectangular cross section
EDM Burrs	- Spherical
Laser Burr	- Globular

*As noted later the term "uniform length" is used somewhat advisidly since length may actually vary considerably.

Burr toughness is not measured directly. Burr hardness, however, is readily measureable and at least qualitatively can be related to burr toughness. For a given material, higher hardness indicates lower toughness.

Burr hardness by itself reveals little about deformation. It is important to also know the hardness of the workpiece. The burr hardness can then be related back to workpiece hardness and the strain produced by burr formation. Since workpiece hardness can vary noticeably on a single workpiece it is important to measure hardness in the general vicinity of the burr.

Measuring burr hardness requires preparation of metallurgical mounts. Although this is time consuming, these mounts also allow the investigator to measure four other properties:

- Burr thickness at base
- Burr length
- Burr shape
- Grain structure (macro patterns, and metallurgical phase)

The flow lines and the crystalline phase in the burr are further measures of metal cutting mechanisms. A knowledge of burr crystal structure is also useful in chemical and electrochemical deburring. In some metals, work hardening changes the crystal structure to a phase which is more readily attacked by chemicals than the normal state. This allows the work hardened burr to be dissolved faster than the parent metal.

DEFINING THE PROPER STATISTIC

In measuring burr length, both Wang [2] and Kienzle [3] emphasize that measurements of maximum burr length should not be used. In measurements of blanking burrs an average burr length should be used. Wang notes that the repeatability of the average burr length is 50 times greater than the maximum burr length. It is not surprising, therefore, that investigators who attempt to study tool geometry influences by monitoring maximum burr length find little correlation. This same effect can be observed in measurements of drilling and milling burrs. The maximum burr length should not be used as a burr measurement. Both mean and median measurements will provide more repeatable and explainable results.

BURR VARIABILITY

Burr properties vary considerably from part to part and even within the same part. As a result it is essential that several measurements be made at each condition tested. Wang's study of blanking burrs [2] indicated

that 24 measurements on each slug are required to provide a positive "average" measurement. While 24 measurements per part may seem excessive it does re-emphasize the one dominant property of burrs - they vary considerably in size. As an example an abusive facing milling operation in 303 Se stainless steel produced an average burr length of 0.0095 inch (Table 1). Measuring 100 edges, however, would reveal lengths varying from 0.0 to 0.020 inch ($\bar{x} \pm 2\sigma$).

Blanking is considered to be one of the more repeatable manufacturing processes. If multiple measurements are required to define a useable blanking burr property, it is obvious that multiple measurements are mandatory when measuring drilling or milling burrs.

In studies of burrs produced by small drills essentially two averages are taken. After cross sectioning each hole two views of the same burr are revealed. The thickness of these two burrs are pooled to give an average burr thickness. This is repeated on three to ten specimens and the average of the averages is used. Although not immediately evident the average within a specimen provides a statistically more reliable quantity than using the individual measurements. This same technique can be used to advantage on other burr properties.

Most tools including dies tend to produce a highly erratic burr during the first few cuts. For this reason any test involving burr measurements should utilize tools which have been "worn" in.

MEASUREMENT TECHNIQUES

Blanking Burrs*

Conventional blanking typically produces a triangular shaped burr. While the triangular shape is also produced by other operations, the mechanism forming the burr is essentially unique to blanking. Kienzle [3] and Seidenbery [4] illustrate the shape of these burrs, and references [2, 5-9] briefly describe how these burrs form or how their size varies with process variables. While no data is available on blanking burr thicknesses, it is reasonable to assume for this type of operation that thickness is proportional to length. Thus burr length can be used as an effective measure of burr thickness for burrs produced in blanking.

Blanking burr height (length) can be measured by mechanical indicators [2, 4, 9] or by optical microscopes [4]. While burr thickness can be measured by slow traversing profilometers [2], metallurgical mounts

*Blanking as used here includes all piercing and stamping operations.

TABLE 1
COMPARATIVE BURR SIZES GENERATED
BY MILLING OPERATIONS

<u>Material</u>	<u>Condition</u>	<u>Burr Thickness, in.</u>	<u>Burr Length, in.</u>	<u>Hardness, Knoop Parent Material</u>	<u>Burr</u>
Aluminum	Abusive Face	$\bar{x}$ 0.0078	0.0138	115	129
	Milling	σ 0.0011	0.0045	4	9
	Gentle Profile	$\bar{x}$ 0.0023	0.0015		
	Milling	σ 0.0003			
Low Carbon Steel	Abusive Face	$\bar{x}$ 0.0046	0.0255	230	275
	Milling	σ 0.0010	0.0191	7	17
	Gentle Profile	$\bar{x}$ 0.0014	0.0024		
	Milling	σ 0.0002	0.0009		
Stainless Steel(303 Se)	Abusive Face	$\bar{x}$ 0.0049	0.0095	305	428
	Milling	σ 0.0020	0.0053	0	56
	Gentle Profile	$\bar{x}$ 0.0020	0.0013		
	Milling				
Beryllium Copper	Abusive Face	$\bar{x}$ 0.0045	0.0189	249	268
	Milling	σ 0.0008	0.0017	7	22
	Gentle Profile	$\bar{x}$ 0.0007	0.0016		
	Milling	σ 0.0005	0.0011		

Abusive Face Milling - Dull cutter and .025 in. 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)

$\bar{x}$ - average measurement

σ - standard deviation of measurements

showing burr cross section provide a more positive method. The profilometer, however, allows one to make several thickness measurements on a specimen while only two measurements can typically be obtained from metallurgical mounts. As pointed out earlier, however, one advantage of the metallurgical mount is that it can also be used to obtain burr hardness.

In most production applications burr hardness should be measured such that an average hardness is obtained. This hardness should be measured at the juncture of the burr and the parent material (Figure 1). The necessity for using an average value can be appreciated by viewing Figure 2. As in the bending of beams this strain is linearly proportional to the distance from the neutral axis. The strain in the roll-over burr shown there varies considerably across the thickness. Since hardness and strain are directly related* hardness will also vary across the burr cross section. While the roll-over burr is only one of four types of burrs, a similar hardness variation will be observed in the other types. Burrs in all materials tend to be harder than the parent material. This is a result of work hardening. By the nature of blanking and machining operations, both the workpiece and the scrap are strained in the vicinity of the burr and this straining hardens the sheared area. The majority of workpiece materials tend to be work hardening to some extent.

The measurement of hardness on burrs which are typically 0.0005 - 0.0020 inch thick requires a micro hardness tester. A Tukon tester with a Knoop indenter is probably the most universally used combination. A 100 gram load is typically used, because of the small area available for indentation.

*See for example [1].

Kienzle [3] recommends measuring burrs on the slug rather than the perforated part, for the sake of simplicity and uniformity. Theoretically the burr on the perforated part should be similar to the one on the slug.

Drilling Burrs

The burrs formed at the entrance of a hole tend to be similar in size and shape to blanking burrs. They are basically triangular, reasonably uniform in size and thus measureable by the same techniques used for blanking burrs.

Drill-exit burrs, however, fall into four basic categories:

- Small uniform burrs
- Exceedingly large but uniform burrs
- Large ragged burrs
- Burrs connected to a cap of material

Most small burrs can be measured by the techniques already discussed. Occasionally when a drill is very dull it will extrude a large burr. This burr which looks like the lip produced on sheet metal flanged holes can easily be measured in a metallurgical mount, with little need to take multiple length measurements. As this type of burr is an indication of poor machining technique it should seldom be seen in production.

The majority of drill exit burrs are very uneven, ragged burrs.* Obtaining repeatable measurements is difficult on these burrs. Because of the flexibility and unevenness of these burrs, mechanical height indicators are not usually feasible. Because the length of these burrs may vary by a quarter of an inch it is important to use a functional definition of burr length. Some of the possible definitions include:

- The minimum burr length
- The median burr length
- The maximum burr length
- The average (mean) burr length

As indicated before the maximum burr length should not be used. It is not a repeatable statistic. The minimum burr length is probably the best attribute to measure if one is limited to a single length measurement per hole. The median burr length is the most repeatable attribute. This can be measured quickly by optical means if the inspector is allowed to

*See for example [10] .

exercise his judgement in determining the median. An average burr length can be used but the occasional large "spikes" which inevitably occur will greatly influence the results. For tests which warrant high accuracy and speed a combination coordinate measuring machine and mini computer can be used to determine average or median values.

After length measurements have been made metallurgical mounts can be used to obtain the remaining burr properties.

Some drills in some materials leave a "cap" of material attached to one side of the hole [11]. While this requires some additional effort to remove, the cap itself should not be measured. A study of the cap, however, may provide some additional insight into burr formation.

Milling Burrs

Like drilling, milling produces several types of burrs. At a given speed and feed in fact, an end mill can produce ten different burrs. Eight of these burrs can be seen by making a full diameter slotting cut through a piece of metal. A burr will be found on each of the eight edges produced. Each of these burrs have different properties.

The long roll-over burr, formed as the cutter exits from the cut, tends to be brittle. It is best measured optically. Because most of these burrs are easily broken off specimen must be handled carefully.

On some materials the burrs are small enough that profilameters can be used. On most materials, however, end milling burrs are so ragged that optical measurements of length are required. On feather-like burr projections the burr length is measured at the base of the projection. As such the projection is essentially pushed down to form a level surface (Figure 3). The remaining burr properties are measured from metallurgical mount.

Grinding, Turning, and Broaching Burrs

Grinding burrs are easily broken off and as such measuring them optically may be the only way to obtain measurements. Small samples can be potted in a plastic matrix prior to sectioning to preserve the burr for a metallurgical examination.

Turning burrs tend to be small but often these burrs are curled over. As a result only a metallurgical mount will provide accurate data on these burrs. The exit burr in broaching also is frequently curled and thus requires the use of a metallurgical mount.

EDM Burrs

These small spherical burrs can be measured either with indicators or metallurgical mounts. From a production standpoint several measurements made along an edge with an indicator should be adequate since the burrs are spherical, and thus width can easily be deduced from height measurements.

EXPERIMENTAL APPROACH

Measuring burrs is time consuming. When the object of a study is to determine how process variables affect burr properties it is essential to utilize an efficient test program. Factorial design approaches such as described by Wang [7, 12] and Davies [13] will greatly reduce the number of specimen which must be analyzed. In addition this experimental approach will unveil combinations of variables which greatly affect the results, but which are not evident in traditional tests.

SUMMARY

The measurement of burrs must be approached as scientifically and carefully as hole size or cutting forces. Failure to exercise such effort can easily mask significant relationships. Careful consideration of property definitions and measurement techniques will provide a realistic base for using burr measurements. The measurement of burr properties today will eventually result in significantly lower deburring costs.

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