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Measurement and Effective Deburring for the Micro Burrs in Piercing Operation

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ABSTRACT

In piercing operation for small hole in very thin plate, micro burrs are formed. The micro burr is very difficult to remove because the thin plate is to be deformed during deburring and deteriorate accuracy. As a first step to remove the micro burrs effectively, the burr must be measured accurately as much as possible. For most micro burrs are so small as less than 10 μm, it is very difficult to measure. Several methods are reviewed to measure the micro burr formed in piercing operation from very thin plate with thickness less than 0.1mm. Also the effective deburring methods are reviewed. Barreling, ultrasonic and chemical deburring methods are performed and the results are compared.

Key Words: Piercing operation, burr, deburring, laser confocal system, die wear, ultrasonic deburring, chemical deburring

1. Specification of burrs in piecing operation of thin plate

Geometry of the Burr formed in metal cutting is decided by the amount of plastic deformation which is determined by depth of cut, tool rake angle and the shape of cutting edge[1,2]. Similarly the size of burr formed in blanking operation is determined by amount of deformation which is determined by clearance and the shape of edges of dies and punches. In the case of piercing of thin plate, the ratio of clearance to thickness of plate becomes one of the important factors for burr size. Several special features of burrs in piercing operation of thin plate can be specified as follows.

Smaller the thickness of plate, smaller clearance must be applied for small amount of plastic deformation. Therefore the burr size becomes very small due to small plastic deformation zone. For example, if the clearance in piercing of thin plate is 10% of the thickness, 0.1 mm, the burr size will be less than 10 μm, which is called as micro burr in this paper. The purpose of this study is to review the methods for measuring the size and geometry of micro burr effectively.

Usually burrs are composed of fractured surface which is formed as a result of shearing operation after plastic deformation. The surface of burr is very irregular and rough due to the fractured surface. This kind of surface makes it difficult to be measured accurately. It will not be reliable to determine the global burr size using the burr size measured in local area. One more special feature of burr in piercing of thin plate is that the shape of burr is very sharp and very weak at the end of burr. It will be liable to be deformed at the end of burr due to the pressure when using contacting method. Therefore the non-contact measuring method is more desirable usually.

In this study, several methods for measuring the micro burrs formed in piercing of thin plate will be reviewed and compared. If the burrs formed in thin plate can be measured accurately, the regrinding period of punch and dies used in piercing operation

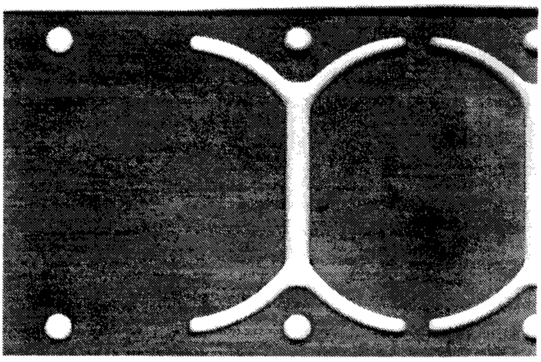


Fig. 1(a) Sample for piercing with 0.3mm thickness

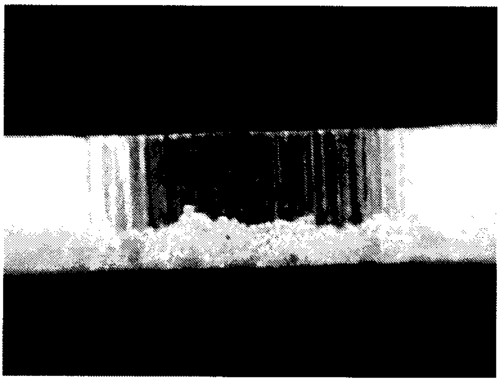


Fig. 1(b) Observation of cross section after piercing operation

can be controlled to guarantee the edge quality of pierced parts. To measure the wear of punch and die during piercing operation, two holes with 2.5mm diameter are pierced from 0.3mm thickness steel plate as shown in Fig.1(a). Later of this study, most burr measurement will be carried out in this sample. In Fig.1(b), the cross section of the hole is observed. The burnishing area and fractured surface can be found.

2. Measuring Technology for Micro Burrs

To remove effectively the micro burrs formed in sheet metal piercing, accurate measurement of the burr must be carried out in advance. Considering the characteristics of the micro burrs mentioned above, several methods can be nominated. A burr formed in blanking operation in thin plate with 0.3mm thickness will be measured to compare the performance of each method.

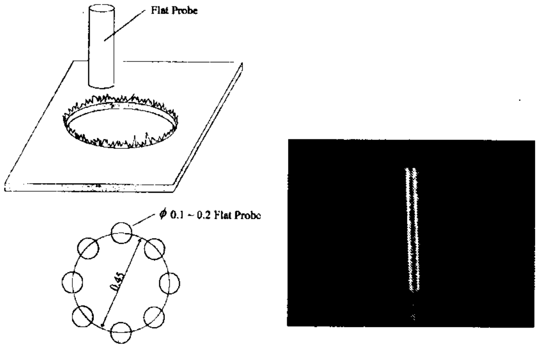


Fig. 2 Burr measurement system with flat end probe with 0.2mm diameter

2.1. Contact Measuring Method (Measuring with a small diameter flat probe)

As a contacting method, burr can be measured by the form coder and surface roughness tester using probe which is contacting with the burr. In using the probe, round tips are preferred to the sharp one due to edge fracture. This makes it difficult to measure accurate geometry of burr. In many cases in production lines, only the magnitude of burr height is enough information to manage the quality of the parts. Usually the piercing operation for sheet metal, the wear of die and punch is examined by the progress of the burr height of parts. To measure the burr height effectively specially in piercing of the sheet metal, the height gage with flat end probe can be used as shown in Fig.2. The measured height means the local maximum burr height within the diameter of the probe. The diameter of the probe determines the measuring area. The resolution of height gage or dial gage determines the resolution of the measurement. Considering the irregularity of the burr geometry, measuring burr by stylus represents the height at a specific point, which is not an adequate tool for burr measurement. As a problem occurred in using probe system, the burr edge which is very sharp usually is to be deformed due to the pressure by the spring force of the dial gage. When use small diameter, this problem becomes more severe in measuring micro burr. However if the burr keeps strength to some extent, no plastic deformation will be occurred. The spring force must be examined for the burr not to be deformed in measuring. Depending on the size of burr or required accuracy in measurement, the diameter of the probe is determined. As a result of measurement, the local maximum value of burr height can be represented along the burr location. A probe with diameter less than 0.1mm is made of tungsten carbide by EDM process.

2.2. Non-contact measuring method using Optics

As non-contact measuring methods, optical method and scanning method are used. For nanometer scale accuracy, scanning method is used by controlling the currency between the sharp probe edge and atoms on the surface of the subject, which is used for high accuracy measurement. For optical method is very simple and easy to be used for high accuracy measurement, recently it becomes popular in application. By controlling magnitude of optical lens, it can be applied to many fields and recently can be used for nanometer accuracy due to the advanced manufacturing technology of optical lens. In this study, main effort will be focused for measuring micro burrs of micrometer scale by optical method. In many cases for measuring micro burrs, non-contact methods are preferred to the contact method for the sharp edge of burr is usually deformed in contact method.

2.2.1 Measurement system using laser confocal principle

In Fig.3, tuning fork moves sensitively to focus automatically on the surface and the moving distance is measured accurately by the sensor, which is the difference in height[3]. When the lens is focused exactly on surface, the reflected light is converged to the pin hole. This mechanism is called as confocal principle. The degree of convergence of the reflected light determines the resolution of height measurement. For the convergence at the pin hole is recognized as the average of the beam spot, the size of beam spot is very sensitive to the resolution of the measurement when the lens focused on the surface exactly. Smaller the size of the beam spot, more sensitive in height measurement. In Fig.4, the burr formed in piercing 2.5mm diameter hole from 0.3mm thickness steel plate is measured by the confocal laser sensor

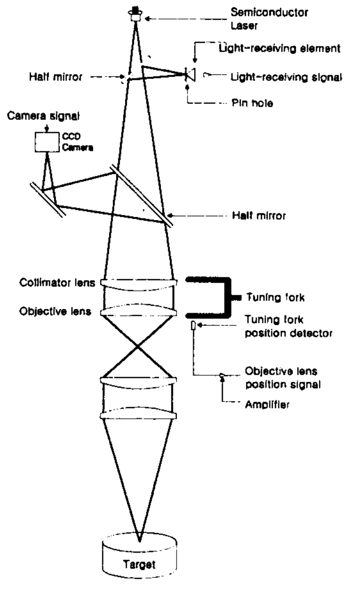


Fig. 3 Laser confocal measurement system

Fig. 4 burr measurement by laser confocal system

and the measured burr height is 8.1 μm. In this system, a part of the reflected light goes to CCD camera and the image of the surface can be shown simultaneously and the size of beam spot is 7 μm. Due to the size of the beam spot, the slope to the top of the sharp edge of burr is very slow by the averaging inside beam spot. The wave length is 670nm and minimum beam spot size is 7 μm. The measurement resolution is 0.2 μm and range is ± 1mm. Measuring method by laser sensor is very simple and accurate, but it is difficult to measure the geometry with sharp edge due to diffused reflection at the tip of the burr. Also 3D configuration of burr is possible by scanning using XY NC table.

2.2.2 Scanning Electron Microscope

As most reliable method to observe micro burrs, scanning electron microscope is used. The burrs can be measured exactly using scale. Usually SEM can be used effectively to measure burr in laboratory but not in factory.

3. Characteristic curve for the prediction of Die wear

To measure the wear of punching die during piercing operation, two holes with 2.5m diameter are pierced from 0.3mm thickness steel plate as shown in Fig.1. The burr in piercing operation depends on quite much on the magnitude of the clearance between punch and die. The clearance is determined at first by the size of the punch and die and also by the deviation in assembly. Secondly the size of the clearance changes according to the wear of punch and die. As it increases, the burr size also increases. Therefore the amount of die wear is predicted by the burr size in piercing. In this experiment the burrs are measured according to the number of blanking operations. To minimize the burr in piercing operation, the critical number of blanking operations must be decided. Even though this process is time consumming, the characteristic curve for the die wear must be determined to maintain the burr size. Tool material is another factor which determines the size of clearance. According to the material properties of tool material, the wear characteristic must be different, which determines different size of burr.

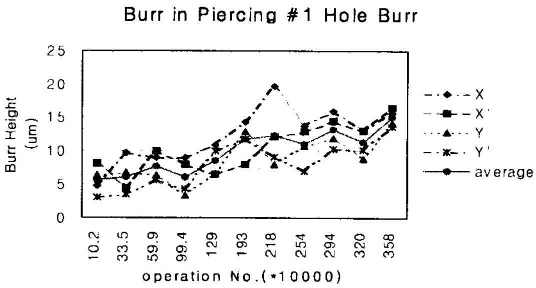
In table 1 , two kinds of material groups are listed for punch and die in piercing 0.3mm stainless steel plate as in Fig.1. For both of die, tungsten carbide is used. For punch material, powder HSS and same tungsten carbide are used. In each group, the tool size and clearance are measured accurately. The size of clearance is controlled as 5% of plate thickness.

Two holes are pierced with different pair of materials as in Table 1. Burrs are measured in each case in the hole made after 3.6 million number of operations. The samples are collected intermittently during operations to measure burr size and cross sectional appearance. To measure the burr size, height

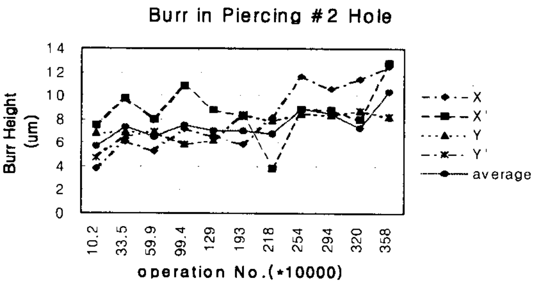
Table 1 Piercing operation conditions

Hole	Tool Material		punch size	die size	gap size (both side)	clear-ance
	punch	die				
Hole#1 (Φ2.5)	Powder HSS	tungsten carbide	Φ2.500	Φ2.532	0.032-4	5.3%
Hole#2 (Φ2.5)	tungsten carbide	tungsten carbide	Φ2.504	Φ2.536	0.032-5	5.3%

gage with 0.2mm diameter probe is used as contact method and laser confocal method is also used to increase the reliability in measurement. In Fig.5(a) and (b), the burrs are measured by laser interferometer method in each hole according to the number of operations. Considering the irregularity of burr geometry, the height is measured at four locations in Fig.5 and also the average value is represented. In Fig.6(a) and (b), the burr heights are measured using height gage with flat end probe using different samples to those for laser measurement. At 16 points along the hole edge, burr heights are measured. In Fig.6(a), the measured heights at same locations as that in laser measurement, location

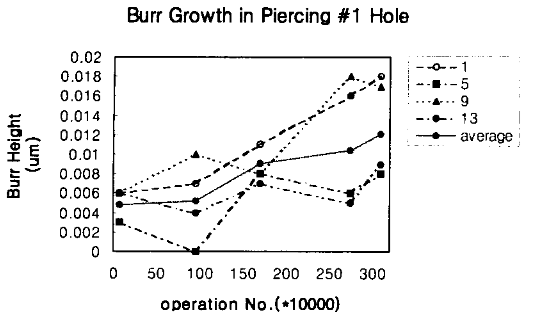


(a) in Hole #1

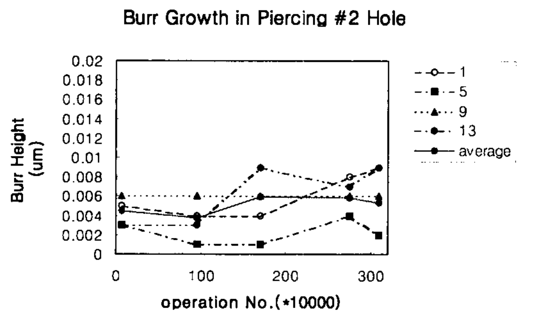


(b) in Hole #2

Fig. 5 Measurement of burr height according to operation number using laser confocal system



(a) in Hole #1



(b) in Hole #2

Fig. 6 Measurement of burr height according to operation number using height gage (flat probe)

number 1, 5, 9, 13, are illustrated to make it easy to compare the measurement result. To make sure the reliability in measurement, the average burr height values are compared in Fig.7 in both holes. Legend, laser1 and probe1, mean the values by laser confocal method and flat end probe system respectively from hole #1. In the same way, laser2 and probe2 mean the values from hole #2. The measurement value by height gage is smaller than that by laser measurement. Intuitively the deformation can be anticipated due to the spring force during the contact for measurement. This phenominon can be observed consistently in all measurements. Therefore the contact method for micro and thin burr is not proper due to the deformation. However the burr with some stiffness can be measured by contact method properly.

In both cases, the burr height growth of average value in hole #1 is more rapid than in hole #2. The growth of the clearance due to wear of die and punch

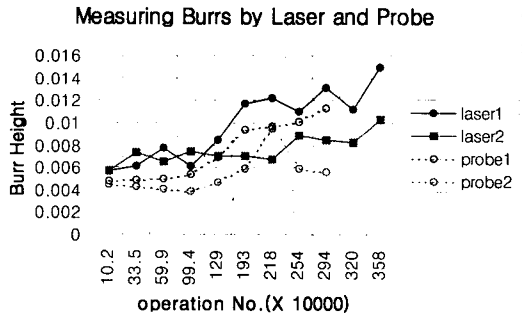


Fig. 7 Comparison of measurement of burr by laser system and height gage with flat probe

is more rapid in powder HSS punch material. In average values, the burr height after 3.09 billionoperations is 0.01212mm in hole #1 and 0.0053mm in hole #2. Conclusionally in this operation, the material group for hole #2 keeps better performance than that for hole #1 from the view point of burr height control. To determine proper combination of tool materials for die and punch, the wear characteristics according to the change of materials can be examined by pin-on-disk experiment. As a conclusion of this part, the characteristic curves for the tool wear prediction under the given operation conditions are determined using curve fitting algorithm as follows.

Burrs are predicted in each hole using the measurement result by height gage as follows

- powder HSS punch/ carbide die
  (clearance : 5.3%)
  burr(μm) = 0.0298 * operation No.(X104) + 4.137
- carbide punch/ carbide die
  (clearance : 5.3%)
  burr(μm) = 0.0135 * operation No.(X104) + 4.677

Even though this relation requires time and money to be determined accurately and also it is difficult to be applied directly to other operation conditions, it is necessary to try to obtain this kind of characteristic curve to control the wear of die and punch quantitatively. And ultimately with the result from pin-on-disk experiment, the general relations can be derived considering tool material and operation conditions like clearance size and workpiece thickness.

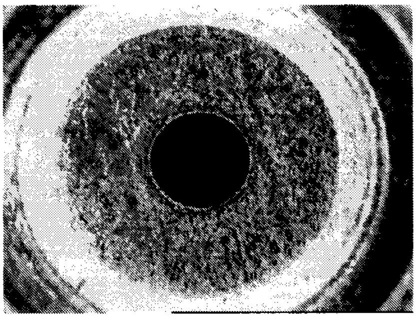


Fig. 8 pierced plate with thickness 0.07mm and 0.45mm diameter

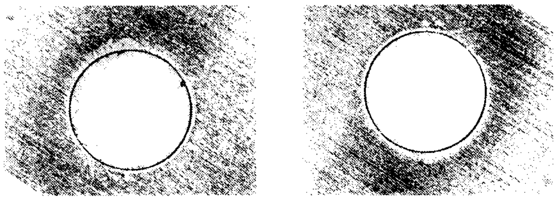
4. Application of ultrasonic deburring for the burr in piercing operation

The burr in blanking operation is determined by the plate thickness, clearance size and operation speed. Once the burr is formed, it must be deburred in acceptable geometry or size. To determine deburring method for the burr in piercing operation, following factors are to be considered, thickness and geometry of plate, material property of plate, tolerance of part geometry and location of burr[4].

In our concern, two kinds of plates are considered. One is the plate with 0.3mm thickness for piercing holes with 2.5mm diameter as shown in FIg.1. Another plate is 0.07mm thickness for piercing holes with 0.45mm diameter as shown in Fig.8. In each case, the deformation during deburring must be examined. As usual methods, barreling, chemical deburring and ultrasonic deburring are conducted and the results are evaluated. Usually barreling method is used for the burrs which is located outside of parts and contains quite large stiffness[5]. Because large mechanical force is exerted, the deformations in thin plate is liable to happen. For our cases, ultrasonic deburring and chemical deburring are applied. Basically most factory does not want to use the chemical deburring due to the environmental problems even though it has good performance in deburring.

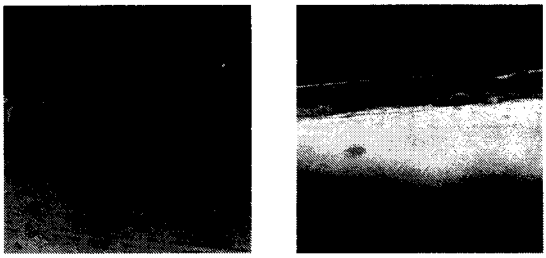
(1) In piercing 0.3mm thickness plate for 2.5mm diameter hole

The burr in stainless steel plate with 0.3mm thi



(a) before deburring (b) after ultrasonic deburring

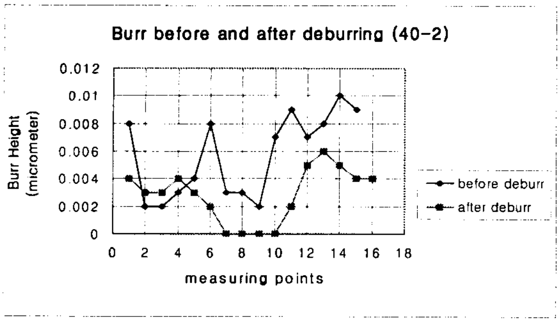
Fig. 9 Burr Formation in Piercing 0.3mm Plate and Result of Ultrasonic Deburring



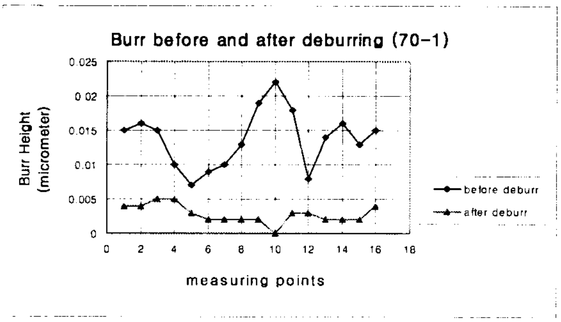
(a) Burr after 2,100,000 operations in hole #2 before ultrasonic deburring (b) Burr after 3,600,000 operations in hole #2 after ultrasonic deburring

Fig.10 Observation of burr before and after ultrasonic deburring using SEM with ×2000 magnitude

ckness in Fig.1 is used to be deburred. In applying the ultrasonic deburring, water is used as detergent and the 25khz vibration is applied for 3 minutes[6]. In Fig.9 the macroscopic figures for before and after ultrasonic deburring process are observed. Even though the cleaning effect can be observed easily, the deburring effect can not be easily seen. To observe more detail, the burrs before and after deburring are observed in Fig.10 using SEM(scanning electron microscope) with 2000 magnitude. It is clear that the burr is not removed basically even though the height of burr reduces little bit. For the burr seems to keep enough stiffness, the height gage as contact method is used to measure the burr height. In two samples, after 2.1 million operations and 3.6 million operations, the burr heights before and after deburring are represented in Fig.11. Burrs are measured at 16 points along the hole edges. Burr in the sample after 3.6 million operations are well deburred than in the sample after 2.1 million operations. Mostly it is observed that the burr height reduces to some extent according to the burr stiffnessbut never removed perfectly in 0.3mm plate.



(a) comparision of burr in sample after 2,100,000 operations



(b) comparison of burr in sample after 3,600,000 operations

Fig. 11 Comparison of burr Height in Before and After Ultrasonic Deburring

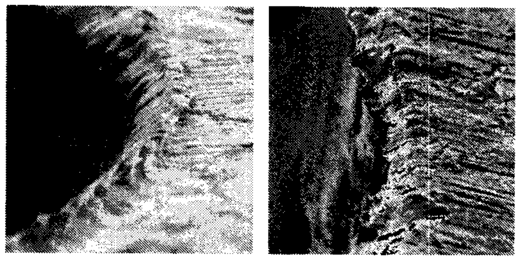
(2) In piercing 0.07mm thin plate for 0.45mm diameter hole

In measuring the burr in piercing 0.07mm thin plate, contact method using height gage is not applicable due to the deformation by the spring force of the height gage. Therefore laser confocal method measured by laser method. The results of ultrasonic deburring in three holes listed in table 2 are measured and compared with the burr size before deburring. The reliability for the laser measurement system must be validated later more detail. At hole #1, the deburring effect is within the measurement error because the average burr height after deburring is larger than that of before deburring. In hole #2 and #3, the average burr height reduces a little, from 3.37 to 2.31 and from 2.52 to 2.13 μm. To observe the behavior more detail during deburring operations, SEM is used and the result is shown in Fig.12.

Pictures are taken in 3000-4000 magnitude. The burrs are apparently observed before deburring in Fig.12(a). The edge after ultrasonic deburring is very sharp and irregular in shape. Considering the mechanism of ultrasonic deburring by the expansion of cavitation, the bending moment by the explosion will be exerted to the projected part. As a result of the repetition of the bending moment, the burr part is broken and shows very rough surface in Fig.12(b). From the detail observation of the figure, the reason for the small reduction of the burr height after deburring can be explained. Even though the projection part of the edge is broken, the main deformation part around hole which contains large strength can not be removed in a similar reason as in 0.3mm plate.

Table 2 Measurement of burr in 0.07mm plate using laser confocal method

	measured points	Hole #1	Hole #2	Hole #3
before deburring	X	2.04	1.94	2.61
	X'	4.36	3.96	2.84
	Y	1.70	4.96	2.70
	Y'	3.60	2.62	1.92
	average	2.93	3.37	2.52
after deburring	X	3.11	0.58	1.33
	X'	4.16	3.10	3.28
	Y	2.80	1.48	2.45
	Y'	5.04	4.06	1.44
	average	3.78	2.31	2.13



(a) Before ultrasonic deburring (b) After Ultrasonic Deburring

Fig. 12 Observation of burr before and after ultrasonic deburring using SEM with $\times 3000$ magnitude in piercing hole with 0.065mm thickness

As an usual method to improve the deburring efficiency, chemical deburring is applied. The result of chemical deburring is shown in Fig.13. Very clean deburring can be observed as expected. However the chemical deburring keeps the problem that it pollutes the environment and also it is very careful to keep the chemical composition and processing time exactly

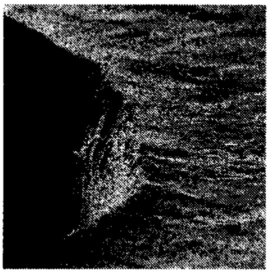


Fig. 13 Observation of burr after chemical deburring using SEM with ×3000 magnitude in piercing hole with 0.065mm thickness

to prevent excessive chemical reaction. Even now many companies are using the chemical deburring method, it is urgent to find non toxic deburring method. From that point of view, ultrasonic deburring has good potential if its deburring efficiency can be improved. More studies are necessary for the deburring for the very thin plate.

5. Conclusions

(1) For the micro burr whose height is less than 10 μm, several measurement methods are applied and analysed. As contact methods, height gage and contracer can be applied. As non contact method, laser confocal method and SEM are used. As conclusion, laser confocal method can be used for the measurement of the micro burr successfully in 0.07mm thin plate. If the burr keeps enough stiffness as in 0.3mm plate, height gage with flat probe as contact method can be applied. However the measurement by contact method shows reduced burr height compared to that by laser method due to deformation during measurement.

(2) To minimize the burr formation during piercing, the wear of punch and die is to be measured and controlled. The burr size development is observed in piercing operation. From the characteristic curve for the burr size according to the operation number, linear relations between operation number and burr size are determined in every combination of die and punch material. The progress of wear in tungsten carbide punch is much slower than that in HSS punch.

(3) Ultrasonic deburring method is applied to remove the burr in 0.3mm and 0.07mm plate. In 0.3mm plate only cleaning effect can be observed. However in 0.07mm plate deburring effect can be observed, which is not satisfactory for perfect deburring. Chemical deburring shows very good performance in edge quality. Considering the water pollution, the ultrasonic deburring must be improved to replace the chemical deburring.

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