Burr Control in Meso-Punching Process

Hong Gue Shin, Yong Seung Shin, Byeong Hee Kim* and Heon Young Kim
Division of Mechanical Engineering and Mechatronics, Kangwon National University,
192-1, Hyoja-dong, Chunchon, Gangwon 200-701, Korea

The shearing process for the sheet metal is normally used in the precision elements such as semi-conductor components. In these precision elements, the burr formation brings a bad effect on the system assembly and demands the additional de-burring process, so this imposes high cost on manufacturing. In this paper, we have developed the in-situ auto-aligning precision meso-punching system to investigate the burr formation mechanism and ultimately minimize burr. Firstly, we introduced the punch-die contact sensing method to align the punch and the die at initial state prior to the punching process. Secondly, by using the low-price semi-conductor laser, burr formed on the edges is measured intermittently during the punching process. We could, finally, make burr on the sheet metal uniformized and minimized by controlling of the precision X-Y table, 1 μm resolution, and measuring burr height by semiconductor laser. Experimental results show the validity of our system for pursuing the burr-free punched elements.

Key Words : Alignment, Burr, Laser Measurement, Meso-Punching

Nomenclature

H_b: The burr height
h_i : The initial distance between the laser diode and the sheet metal
r_s : The beam spot

1. Introduction

In recent years, since most high-tech products become smaller, lighter, more complex and precise, the importance of the unexpected shearing defects repression gradually increases. Especially, the burr has been known as the most serious defects in micro scale shearing processes including punching, blanking, piercing, etc. Unfortunately, since it is difficult to obtain the burr-free results when shearing the tiny precision parts, the finish-

ing operation, such as deburring, edge-rounding or blending, etc., is necessary, in general, to remove the burrs on the sheared edges. Gillespie (1979) pointed out that deburring and edge finishing can cut down expense as much as 30%. These additional deburring steps impose high cost on the post-shearing processes. Therefore, the burr formation should be minimized to reduce the cost of deburring and maintain the precision of the part. In order to minimize the burr formation, basically, the effect of shearing parameters needs to be investigated.

Since the first patent by Fritz Schiess, many researchers have investigated the effects of shearing parameters. Chang and Swift (1950) carried out the experimental investigation on effects of the clearance and the edge sharpness for several industrial metals. Johnson and Slater (1967) performed a comprehensive survey concerning the effects of punch speed and temperature on blanking. The effect of clearance (Holiga, 1965), the critical punch travel distance criteria for the onset of cracking (Atkins, 1980), the influence of sheared-edge profiles (Choy and Balendra, 1996) and

---
* Corresponding Author,
E-mail : kbh@kangwon.ac.kr
TEL : +82-33-250-6374; FAX : +82-33-257-4190
Division of Mechanical Engineering and Mechatronics, Kangwon National University, 192-1, Hyoja-dong, Chunchon, Gangwon, 200-701, Korea. (Manuscript Received November 4, 2004; Revised February 4, 2005)

lots of investigations have been reported by many researchers.

There have been few studies, however, on the thin sheet metal shearing process. Lee et al. (1997) investigated the parameters in dam-bar cutting of integrated circuit packages, Li (2000) reported experimentally the cut surface quality and burr height variations with respect to the off-the-plane blade angles, the clearances and the blade sharpness, as well as the angles of the blade travel direction with respect to the sheet plane, and size effects in processing of thin sheet metal shearing are also demonstrated by Raulea et al. (2001).

Among many parameters, the clearance has been known as the most important parameter to control. Therefore, especially in thin metal shearing, the clearance between the punch and the die is minutely controlled and balanced by the precision aligning/moving mechanism.

In this study, we have developed a precision in-situ aligning meso-punching system. For minimizing and uniformizing the burr formation, we introduced the two-step punch-die aligning method. The punch and die can be aligned initially by the punch-die contact sensing function. The low cost semiconductor laser has been embedded in the meso-punching system to measure the confront burr height and the in-situ alignment of the punch and die. With this confronting burr balancing process, the small and uniform burrs can be obtained automatically. In addition, the burrs formed on the sheared edge can be monitored during the shearing process via the DAQ system for data acquisition.

2. Burr Formation and Sheared Edge

2.1 Burr formation mechanism

Fig. 1 shows the mechanism of burr formation during the thin sheet metal shearing process. The crack initiates from the top initial indent point **A** and connected with the crack propagated from the bottom initial indent point **B**. This crack propagation mechanism makes burrs (Li, 2000). As mentioned before, the clearance between the punch and the die is the most important parameter in the burr formation mechanism. Generally, when the clearance decreases, the height of the burr decreases. But there is a limitation to decrease the clearance.

2.2 Sheared edge

As shown in Fig. 2, the sheared surface consists of 4 characteristic zones : 1) the roll-over zone which is the part of the edge that is drawn into the sheet by the punch ; 2) the burnished zone formed by the punch before the onset of ductile fracture ; 3) the fractured zone which has a rough surface formed by ductile fracture when the punch progresses through the sheet ; and 4) the burr.

Because of the sizes of ductile fracture much bigger than the fracture zone and burr, it cannot be predicted by empirical models. From the manufacturing point of view, however, they are often the most important quality parameters (Li, 2000).

2.3 MESO-punching system
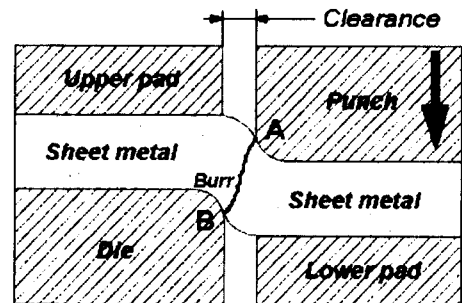
In order to minimize and uniformize burrs and
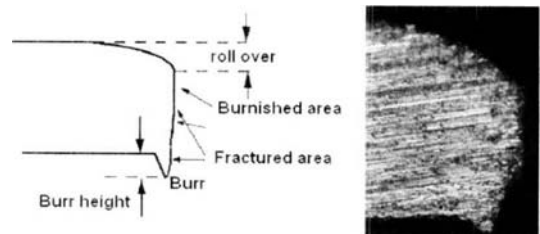

Fig. 1 Shearing mechanism

Fig. 2 Cross-sectional view of sheared edge

ultimately to get the burr-free parts, we have developed the PC-based numerical control meso-punching system which including the two step punch-die auto-aligning function and the precise burr measuring function as shown in Fig. 3.

2.3 System construction

The developed precision punching system can punch out the various shaped holes by changing the shapes of the punch and the die, such as square, circle, oval, rectangular, etc.
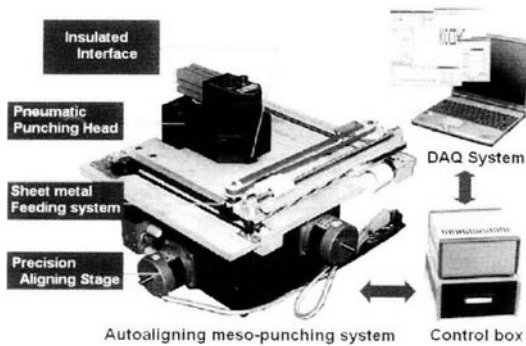

Fig. 3 Auto-aligning meso-punching system

As shown in Fig. 3, the system can be separated into three components ; the punching head set, the sheet transfer part, and the aligning device between the punch and the die. The alignment system includes the X-Y table with the 1 μm positioning accuracy and two photo couplers. The system is also able to monitor the state of the punching operation by sensors and the micro-processor. The control values and the monitoring results are transmitted to the personal computer by the RS232C serial communication and the motion control board.

For the precise punch-die alignment, the system has two aligning functions, the punch-die contact sensing function for the initial alignment and the confronting burr balancing function for the in-situ alignment.

2.5 Initial alignment function

In order to control the burr formation precisely, it is essential to control the initial size of the clearance. In this paper, the simple punch-die contact sensing function is introduced for the initial alignment of the punch and the die. The
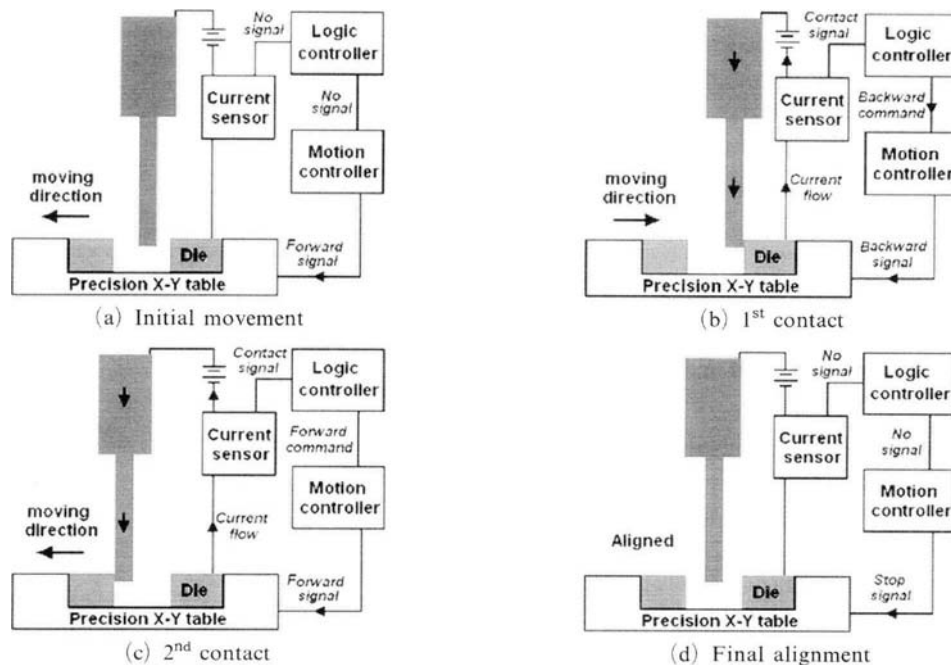

Fig. 4 Initial punch-die alignment procedure

basic principle of the alignment is shown in Fig. 4.

The initial position of the punch is arbitrarily set up against the die hole. Therefore, the clearances between the punch and the die are apt to be irregular at four sides; up, down, right and left. If the punching operation is carried out under such a condition, burrs on the four edges of the punched hole might have different sizes and heights.

For the purpose of the alignment, therefore, the electric ON/OFF signal recognizing technique has been adopted. The electric insulation film (Teflon®) was inserted between the end retainer and the lower base so as to induce the electric insulation between the punch and the die.

As shown in Fig. 4, the process of aligning method is as follows; 1) The X-Y table moves toward +X until punch contacts the die; 2) After first contact, the table goes backward to the opposite direction before the new contact signal is detected; 3) The distance between first contact point and the second one is calculated by using electric pulse signals; 4) And then the X-Y table moves to the center of both points. To improve the positioning accuracy, the effects of the backlash and the stick-slip of the driving system were compensated experimentally. Though the initial current is set to 5V and comes down to 0V when the contact happens, the electric current goes down near 0V when the punch approached to the die in a few micrometers without the non-contact state. To reduce these errors, lots of experiments were carried out to find out the standard current.

2.6 Laser in-situ alignment function

For the purpose of the in-situ control of the burr formation in the shearing process, the precise measurement of the burr should be preceded. But, it is hard to measure the burr on the sheet metal correctly because of its relatively small size and high sharpness.

The burr measuring methods, generally, are classified into two categories; the contact and the non-contact method. In case of the contact method, the burr height is measured by scratching a probe with very small diameter across the ridge of the burr. The sharp probe or burr edges are easily damaged during burr height measuring because of the friction and the impact between the burr and the probe, and it gradually makes the measuring accuracy worse. On the other hand, the non-contact measurement using the optics, such as a laser, is more convenient to measure the burr.

2.7 Principle of laser measurement

Figure 5 presents the laser probe (OMRON Z4M-N30V, wavelength: 670 nm; measuring range: 28~32 mm; and spot size: 60~100 μm) and the

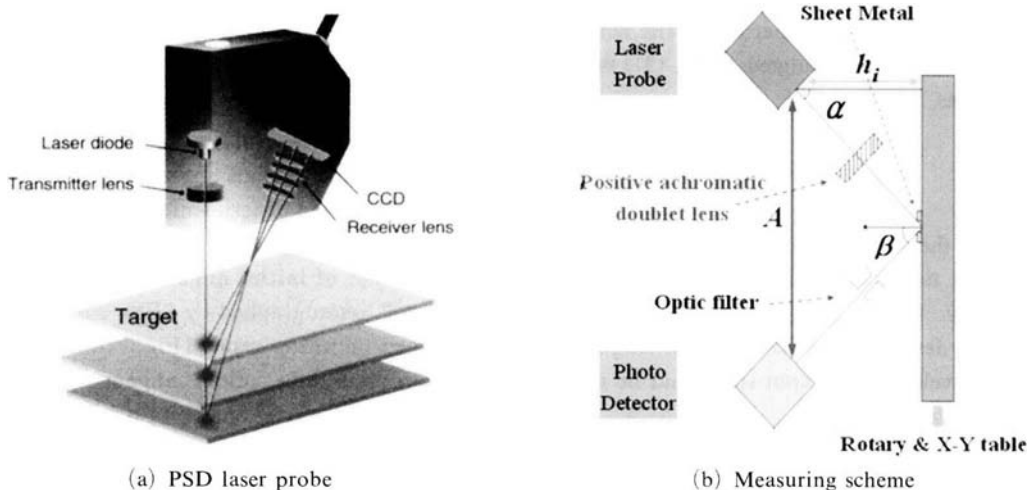(a) PSD laser probe   (b) Measuring scheme

Fig. 5 Principle of non-contact burr measuring method

principle of the burr measurement. The rays of light came from the light source are concentrated by the transmitter lens into the target, and the reflected rays are projected on the PSD (Position Sensitive Detector) through the receiver lens. According to the length between object and transmitter lens, the reflected ray phases of object are projected to the different position on the PSD, and the signal is linearly converted into the current of 4~20 mA in proportion to the position. The burr height is not measured by the intensity of light or the interference, but by geometrical method with the 2 output split diode. From Fig. 5(b), the length between the laser probe and the object, h, is obtained as following Eq. (1).

$$h = \frac{A}{\tan \alpha + \tan \beta} \qquad (1)$$

where A is the distance between the laser emitter and the receiver. Consequently, the burr height, H_b, can be calculated as ;

$$H_b = h_i - h \qquad (2)$$

where h_i is the initial distance between the laser diode and the sheet metal.

However, it is somewhat difficult to measure the size and the shape of the extremely sharp and small burr because of the size effect of the beam spot. To overcome this limitation, we introduced the achromatic doublet lens, as shown in Fig. 5 (b), between the laser probe and the object. If the light exactly fills the aperture of the lens, the beam spot r_s can be calculated as Eq. (3) (Wilson and Hawkes, 1987).

$$r_s = \frac{2}{\pi} \lambda \frac{f}{D} \qquad (3)$$

where λ is the wavelength, f and D are the focal length and the diameter of the achromatic lens respectively. In this study, by using the $\phi 12.7$ achromatic lens with the 25 mm focal length and 670 nm wavelength, the spot size could be reduced to 1~2 micrometers.

2.8　In-situ aligning method
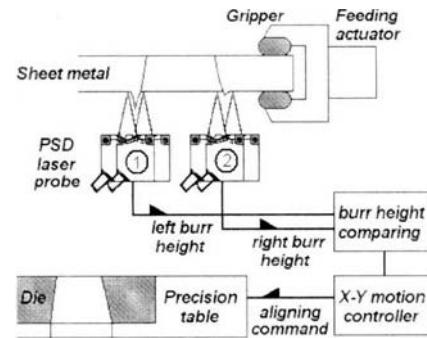In order to measure and compare the burrs on

Fig. 6　Principle of in-situ alignment

the sheet metal during the punching process, the laser probe system is mounted under the X-Y table. Fig. 6 shows the principle of the confront burrs measuring scheme and the in-situ alignment. The aligning procedure is as follows ; 1) Intermittently, the sheet metal is fed to the designated position by the feeding actuator ; 2) Burr heights at the position ① and ② are measured by the PSD laser probe in succession and the measured data are transmitted to the microprocessor ; 3) The microprocessor calculates the difference between two measured burr heights ; 4) As the precision table is moved to the right or the left minutely according to the value of the difference and the related alignment table (see Table 2), not only the difference but also the absolute burr heights can be minimized and uniformized ; 5) When the aligning procedure finishes, the punching process resumes.

3.　Experiment and Discussion
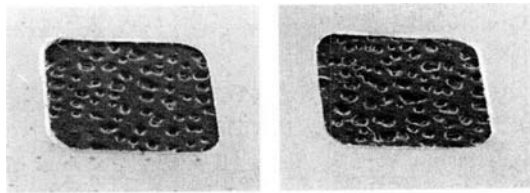
3.1　Experimental condition
To evaluate the validity of the developed punching system, various experiments performed. Table 1 shows the experimental conditions.

3.2　Effect of initial alignment
Figure 7, photographed by SEM, compares the misaligned punching result (Fig. 7(a)) with the aligned one by the initial alignment function (Fig. 7(b)). Materials are the brass and the sheet thickness is 50 μm. The nominal clearance corresponding to the exact alignment of the punch and the die is given by 10 μm. As seen in Fig. 7(a),

Table 1 Experimental conditions

Punch	shape	rectangular	
	dimension (mm)	3 × 3	
	material	WC	
Die	shape	rectangular	
	dimension (mm)	3.01 × 3.01, 3.02 × 3.02 3.03 × 3.03, 3.04 × 3.04	
	material	WC	
Clearance (μm)		5, 10, 15, 20	
Sheet metal	thickness (μm)	50	
	materials	Cu, brass, stainless steel	

Table 2 Compensation value for in-situ alignment

Burr difference (μm)	Shifting distance (μm)
~15	1
15~30	2
31~50	3
51~80	4
81~100	5

(a) Before alignment   (b) After alignment

Fig. 7 Effect of the initial alignment

Fig. 8 Burr height with respect to clearance

the burr and shearing defects are observed on the left sheared edge and the confronting burrs show the discrepancy. This means that the punch and the die are misaligned and the location of the die against the punch is shifted toward the left.

For improving initial alignment condition, the punch and the die were adjusted by moving the precision X-Y table toward the right direction by the punch-die contact sensing method.

As shown in Fig. 7(b), when aligning the punching system prior to the punching process, the quality of the shearing surface increases and the burr height can be remarkably reduced.
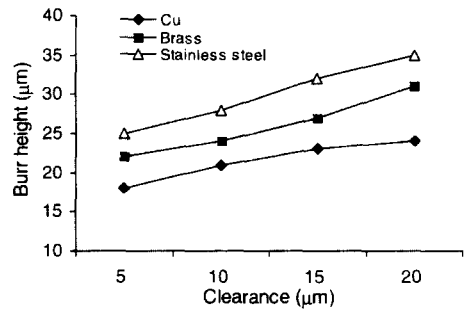
3.3 Burr Height with respect to Shearing Conditions

Figure 8 shows the measured heights of the burrs with respect to the variation of the clearances and the materials with 50 μm sheet thickness. As well known from several researchers' works, when the clearance increases, the burr height increases.

The material type of the sheet metal, otherwise, also makes influence on the burr formation. As shown in Fig. 8, the burr on the edge of the stainless steel is much higher than that of

the copper. It means that the mechanical properties of the material, like the ultimate tensile strength, give a significant effect on the formation of the burr.

3.4 Effect of in-situ alignment

In order to determine the appropriate amount of the table movement for the in-situ alignment, lots of experiments had performed. Table 2 shows the compensation values for the in-situ alignment. For example, if the left burr is 25 μm higher than the right one during punching process, the die should move 2 μm to the right for obtaining the balanced burr.

The effect of the in-situ alignment is shown in Fig. 9. The material is the copper and the sheet thickness is 50 μm. The clearance is given by 10 μm. Even though initially aligned by the punch-die contact sensing function, the accuracy of the alignment would deteriorate gradually while the punching process continues. Therefore, the amount of the discrepancy between the confront burrs increases as seen in Fig. 9(a).

To minimize this discrepancy, the in-situ alignment function was introduced. The height of the burr is measured 5 times by the embedded laser measuring system and averaged in the micro-
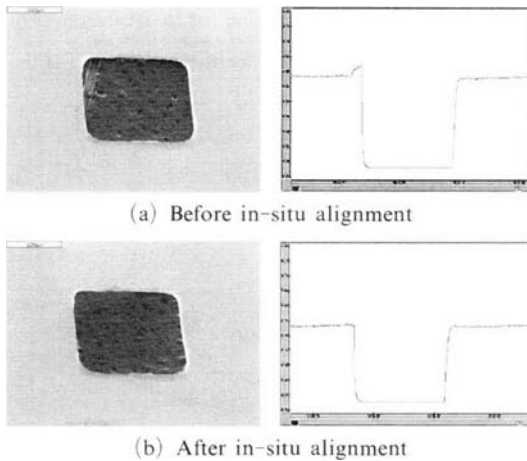
(a) Before in-situ alignment

(b) After in-situ alignment

Fig. 9 SEM photographs and profiles of punched results

processor. From the measured burr height, the difference between the confront burr height is calculated. The difference is 35 μm approximately in this case. In accordance with the measured and compared results, the precision X-Y table is forced to move 3 μm to the right and the punching process continues. Fig. 9(b) shows the punching result after the in-situ alignment procedure has finished.

As you can notice from the photograph in Fig. 9(b), there still remain small burrs. Unfortunately, it is impossible to remove the burr perfectly, especially in case of the thin sheet metals. Consequently, in order to obtain the burr-free sheet metal elements, post processing, like ultrasonic deburring (see Appendix), should be followed.

4. Conclusion

In this study, we developed the precision meso-punching system and introduced two kinds of punch-die auto aligning methods, the punch-die contact sensing method and the in-situ self-aligning method, to uniformize and minimize the burrs formed during the punching process.

The laser burr measuring system was also developed for precise measuring of the burr. But, burr measuring results would have unavoidable errors caused by the size effect of the laser spot

when the burr didn't have enough size. Therefore, to get the more accurate dimensional information of the burr using laser measuring, the spot size of laser can be reduced under 2 μm by introducing the achromatic lens system. Comparing the experimental results before and after aligning, the fidelity of the proposed methods is verified.

References

Gillespie, L. K., 1979, "Deburring Precision Miniature Parts," *Precision Eng.*, 1(4), pp. 189~198.

Chang, T. M. and Swift, H. W., 1950, "Shearing of Metal Bars," *J. of Inst. Metals*, 78, p. 393.

Johnson, W. and Slater, R., 1967, "Survey of Slow and Fast Blanking of Metals at Ambient and High Temperatures," *Proc. of the international Conference of Manufacturing Technology CIRP-ASTME*, pp. 825~851.

Holiga, L. A., 1965, "Punch to Die Clearance," *ASTME 33rd Annual Meeting*, 65(2)

Atkins, A. G., 1980, "On Cropping and Related Process," *Int. J. of Mechanical Sciences*, 22, pp. 215~231.

Choy, C. M. and Balendra, R., 1996, "Experimental Analysis of Parameters Influencing Sheared-edge Profiles," *Proc. of the 4th Int. Conference on Sheet Metal*, pp. 101~110.

Lee, W. B., Cheung, C. F., Chan, L. K. and Chiu, W. M., 1997, "An Investigation of Process Parameters in the Dam-bar Cutting of Integrated Circuit Packages," *J. of Materials Processing Technology*, 66, pp. 63~72.

Li, M., 2000, "An Experimental Investigation on Cut Surface and Burr in Trimming Aluminum Automotive Sheet," *Int. J. of Mechanical Science*, 42, pp. 889~906.

Li, M., 2000, "Micromechanisms of Deformation and Fracture in Shearing Aluminum Alloy Sheet," *Int. J. of Mechanical Science*, 42, pp. 907~923.

Raulea, L. V., Goijaerts, A. M., Govaert, L. E. and Baaijens, F. P., 2001, "Size Effects in the Processing of Thin Metal Sheets," *J. of Materials Processing Technology*, 115(22), pp. 44~48.

Wilson, J. and Hawkes, J. F. B., 1987, Laser Principles and Applications, Prentice Hall, p. 108.

Appendices : Ultrasonic de-burring

It is difficult to remove the burr formed during sheet metal processing by using conventional deburring processes, such as grinding, barrel finishing, etc. Thus, the ultrasonic or the etching processes are generally adopted in order to remove the burr on the sheet metal.

In order to obtain the burr-free punched parts, we used the deburring process using the ultrasonic power and abrasives. Fig. A1 is comparing the conventional deburring method and the novel deburring method, the reversal flow resistance method. The former deburring method like Fig. A1 (a) is not efficient to remove the burr because it uses only the impulse energy of the abrasive against the burr surface to deburr. The sharpness of the burr gives little opportunity of impulsing to abrasives during the deburring process. However, the newly proposed deburring method like Fig. A1 (b) uses both the impulse of the abrasive and the flow resistance of the abrasive slurry. Therefore, deburring is more effective and faster than former methods. And it is convenient to apply to in situ deburring because there is no need to turn the sheet metal over to deburr. Fig. A2 also shows the deburring results when the reversal flow resistance method was used.

(a) Conventional method   (b) Reversal flow resistance method
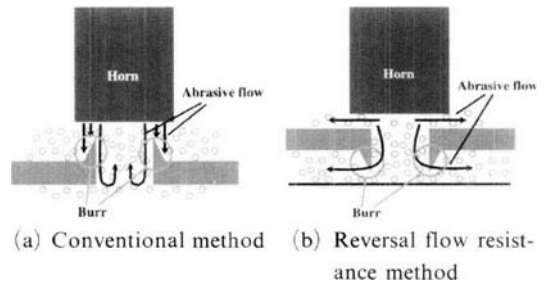
Fig. A1 Two kinds of deburring methods

(a) Before deburring   (b) After deburring
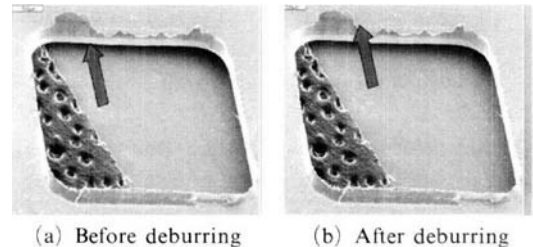
Fig. A2 Effect of reversal flow resistance deburring