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EFFECT OF TOOL DESIGN ON FORMABILITY IN DEEP DRAWING BY APPLYING COMPRESSIVE FORCE ON FLANGE

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Abstract. This paper presents a new deep drawing process which applies compressive force on a flange for forming a deep cup effectively. This method uses a punch with a convex and a die, and optimum tool design was investigated using the finite element method (FEM) in order to prevent the formation of defects. First, the effect of the punch configuration was investigated. As a result, a cup with a uniform side wall thickness was obtained under the condition that the punch convex length was greater than the blank thickness and the punch top corner radius was appropriate. It was possible to obtain the deep cups by decreasing the clearance between the punch convex and the die. However, dimensional accuracy decreased with the decrease in the clearance. Based on these results, two-steps process using a backward punch was proposed, and deep cups having high dimensional accuracy was formed successfully by this method.

1 INTRODUCTION

Various products are manufactured from sheet metals in the industrial fields, such as for automotive components, household electronics, medical instruments and so on. Deep drawing is one of the sheet metal forming methods, and cup shaped products are obtained by this method [1]. Cup-shaped products are used for beverage cans, automobile body panels, motor or battery housings and so on. Although deep drawing is a very popular method, it is difficult to form a deep cup with a wide flange. In deep drawing, the material is drawn from a blank holder into a die by a punch press. This method breaks material easily because the material is stretched by tensional force. Forming a cup becomes difficult when the flange portion is expanded because the tensional force increases with an increase in frictional force on the flange. Therefore, deep cups are generally manufactured by multi stage process [2]. In addition, the deep drawn cup is welded to a holed flange when the flange portion is needed.

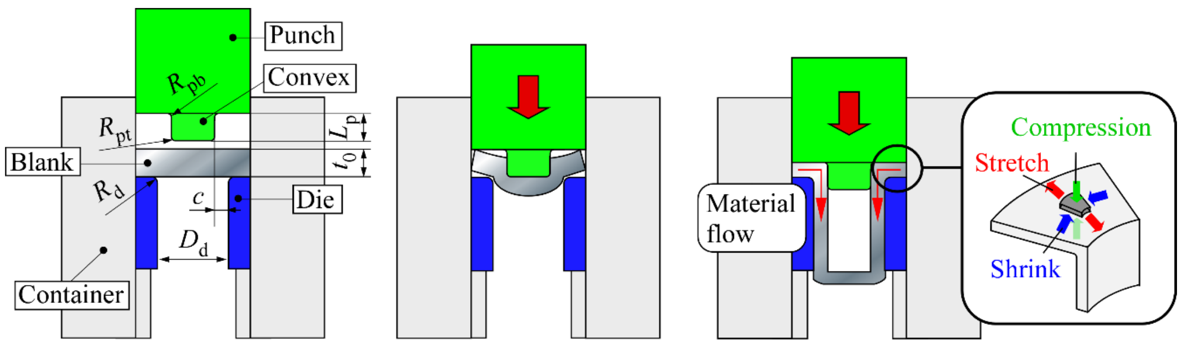
Reduction of the tensional force is important for improvement of the forming limit in deep drawing. For example, the tensional force can be reduced by reducing the frictional force on the flange portion. Lubrication is important for reducing the frictional force. Horikoshi et al. developed a method using a high-pressure water jet as lubricant [3]. Hatanaka et al. increased the forming limit by reducing the frictional force using a blank having a shape similar to a petal [4]. Other alternatives for the reduction of the tensional force would be methods which apply compressive force on the flange portion. In Maslennikov's method, a deep cup was formed by repetitively compressing the flange using a rubber ring without the punch [5]. Hassan et al. performed a deep drawing with incremental flange compression using a tapered blank holder divided into four segments [6]. However, much time is wasted because the deep cup is formed by iterative compression. In a previous study, the authors developed a new deep drawing method applying compressive force on the flange [7]. In this method, a very deep cup was formed using simple tools in only one step. However, dimensional accuracy of the formed cup was low.

This study investigated the effects of forming parameters, such as a punch configuration and clearance between the punch and die, by the finite element method (FEM) in order to optimize the tool design for improvement of the dimensional accuracy of the formed cup. First, the optimum punch configuration was investigated for suppression of forming defects. Next, the possibility of forming the deep cup was investigated by decreasing the clearance, and dimensional accuracy was evaluated. Based on these results, a two-step process was proposed for suppression of defects and improvement of the dimensional accuracy.

2 DEEP DRAWING BY APPLYING COMPRESSIVE FORCE

Figure 1 shows a schematic illustration of deep drawing by applying compressive force on the flange. Main tools are die and punch with convex, as shown in Fig. 1 (a). The blank is initially stretched into the die by the punch convex, as shown in Fig. 1 (b). After that, the flange portion of the blank starts to be compressed between the punch and the die, then the material in the flange portion is drawn into the die, as shown in Fig. 1 (c). Height of the cup could be controlled by changing the compression amount of the flange. In this processing method, products were formed only by compressive force. Therefore, it is considered that the forming limit is high compared to the general deep drawing method.

In this method, the punch shape is important. For example, when the punch convex length L_p was too long, the blank ruptured during the initial stretching. On the other hand, the material flow could not be controlled when L_p was too short. The clearance c determines the side wall



(a) Set up (b) Initial stretching (c) Compression

Figure 1: Schematic illustration of deep drawing applying compressive force on flange

thickness of the product. A very deep cup with thin side walls could be produced when c is set at a small value.

3 ANALYSIS

An elastic-plastic analysis was carried out by using commercial code ELFEN for FEM (Rock field Software Limited, Swansea). Figure 2 shows the schematic illustration of the model, and Table 1 shows the analysis conditions. The model is two dimensional with axisymmetry. The von Mises yield criterion was adopted, and the normality principle was applied to the flow rule. The constraints were determined by the penalty function method, and an explicit scheme was adopted. Three-node triangular elements with three integration points and adaptive meshing scheme were adopted. During the analysis, we changed punch shape, such as convex length L_p and top corner radius R_{pt}, and clearance c between the punch convex and die. c was aligned by changing the die diameter D_d while the punch convex diameter D_{pc} remained constant. The thicknesses of the side wall t_s and the flange t_f, and height h were measured for evaluating the dimensional accuracy of the formed cup as shown in Fig. 3. Aspect ratio α and compression ratio of the flange thickness β_f and was defined by the following expression.

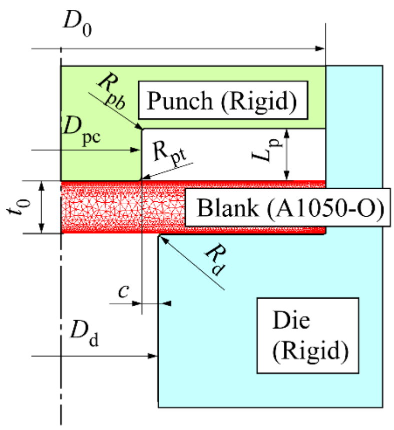


Figure 2: Schematic illustration of analytical model

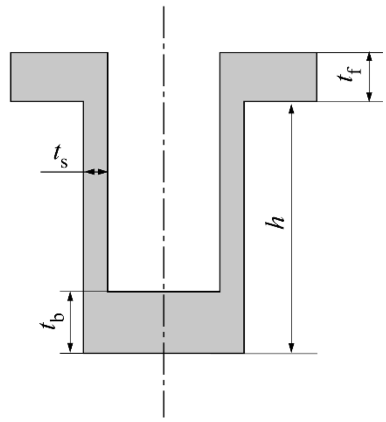


Figure 3: Evaluation of the formd cup

Table 1: Analysis conditions

Material	Blank material	Aluminum (A1050-O)
	Blank diameter D_0 [mm]	30
	Blank thickness t_0 [mm]	3.0
Punch	Diameter D_p [mm]	30
	Convex diameter D_{pc} [mm]	9.0
	Convex length L_p [mm]	1.0~5.0
	Base corner radius R_{pb} [mm]	0.2
	Top corner radius R_{pt} [mm]	0.2~1.0
Die	Diameter D_d [mm]	10~15
	Corner radius R_d [mm]	0.2
	Clearance c [mm]	0.5~3.0
Friction coefficient		0.1

$$\alpha = \frac{h}{D_d} \tag{1}$$

$$\beta_f = \frac{t_0 - t_f}{t_0} \tag{2}$$

4 RESULTS AND DISCUSSION

4.1 Effect of punch convex length

In this experimental series, the effect of the punch convex length L_p was investigated in order to reveal the appropriate punch shape for forming the product without defects. The clearance c was set at 2.0 mm, and the punch top corner radius R_{pt} was set at 0.2 mm. Figure 4 shows the typical cups formed in this investigation. Side wall curved, and thickness t_s was uneven and thicker than the clearance c when L_p was shorter than the blank thickness t_0, as shown in Fig. 4 (a). When L_p was equal to t_0, t_s was uniform and equal to c as shown in Fig. 4 (b). However, a dent was seen at the corner of the bottom due to local thinning during the initial stretching. The thickness at the dent decreased with an increase in L_p, and the blank ruptured when L_p was 5 mm as shown in Fig. 4 (c).

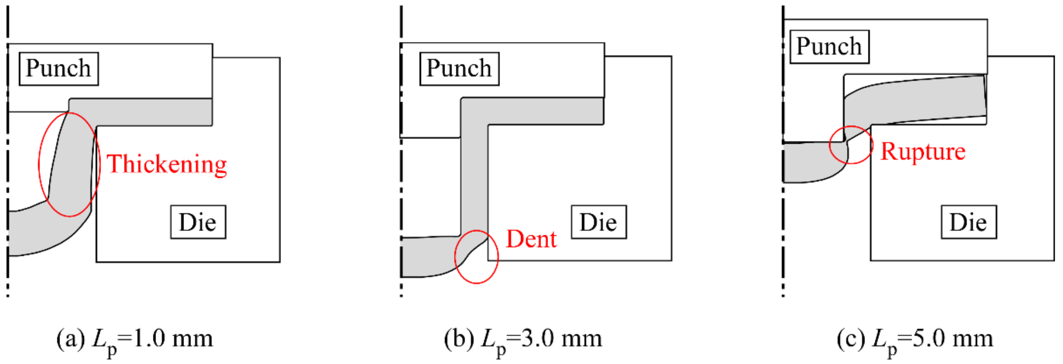


Figure 4: Typical configuration of formed cup (c=2.0 mm, R_{pt}=0.2 mm)

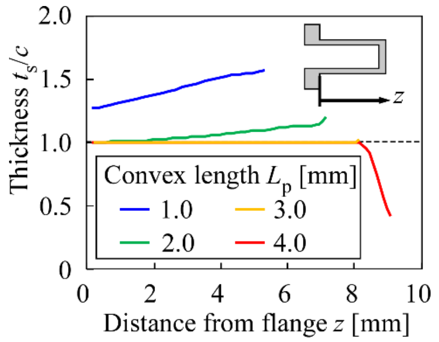


Figure 5: Side wall thickness distribution (c=2.0 mm, R_{pt}=0.2 mm, β_f=0.33)

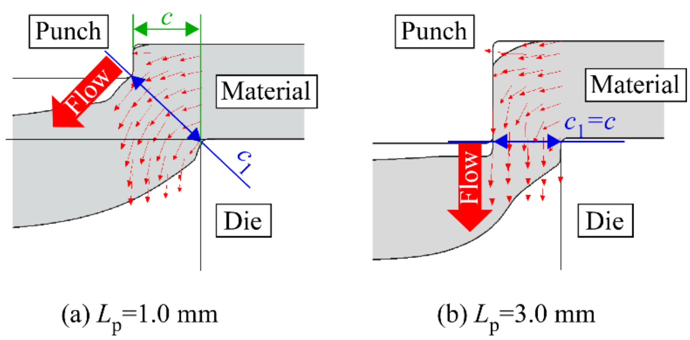


Figure 6: Material flow during flange compression (c=2.0 mm, R_{pt}=0.2 mm)

Figure 5 shows the distribution of the side wall thickness t_s/c when the flange compression ratio β_f was 0.33. t_s/c increased toward the bottom of the cup when L_p was shorter than t_0. The material flowed out from the clearance c_1 between the punch convex corner and the die corner during the compression of the flange as shown in Fig. 6, and the material flow direction and t_s are determined by c_1. When L_p is shorter than t_0, c_1 is larger than c when the flange compression starts as shown in Fig. 6 (a), and c_1 decreases to c while the punch convex approaches the die. When L_p is larger than t_0, a cup with uniform distribution of t_s was produced because c_1 is equal to c during the flange compression, as shown in Fig. 6 (b). However, t_s/c drastically decreases due to the local thinning at the corner of the cup when L_p is long compared to t_0 as shown in Fig. 5. Thus, L_p should be t_0 approximately for forming a cup with good dimensional accuracy.

4.2 Effect of punch top corner radius

Suppression of the dent was attempted by increasing the punch top corner radius R_{pt}. The clearance c was set at 2.0 mm, and the punch convex length L_p was set at 3.0 mm. Figure 7 shows the cup bottom shape when R_{pt} was changed. The dent was suppressed under the condition that R_{pt} was over 0.6 mm by preventing the localized deformation at the portion near the corner of the punch top. However, the side wall thickness t_s/c was large near the bottom in the case of R_{pt}=1.0 mm as shown in Fig. 8. When the flange compression starts, the clearance c_1 between the punch convex corner and the die corner increases with an increase in R_{pt} as shown in Fig. 9. Therefore, the side wall thickened and curved just like the case that the punch convex length L_p was short. From this investigation, the appropriate R_{pt} is 0.6 mm for suppression of the dent.

4.3 Production of deep cup by changing clearance

Production of the deep cup was conducted by decreasing the clearance c. The punch convex length L_p and corner radius R_{pt} were set at 3.0 mm and 0.6 mm, respectively based on the above results. Maximum flange compression ratio β_f was set at 0.83 which reduces the flange thickness to 0.5 mm. Figure 10 shows the maximum aspect ratio α of the formed cup without

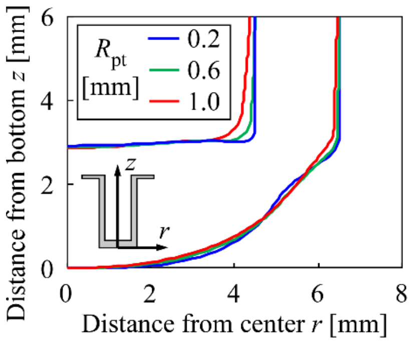


Figure 7: Effect of punch top corner radius on bottom shape of cup (c=2.0 mm, L_p=3.0 mm)

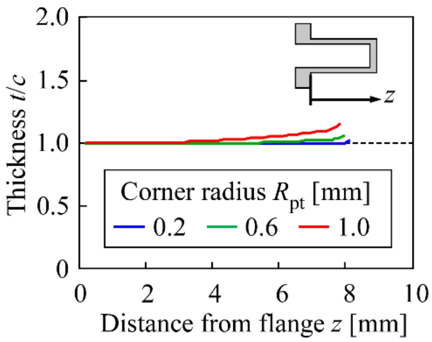


Figure 8: Effect of punch top corner radius R_{pt} on side wall thickness distribution (c=2.0 mm, L_p=3.0 mm, β_f=0.33)

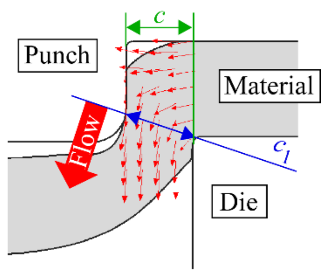


Figure 9: Material flow during flange compression (c=2.0 mm, L_p=3.0 mm, R_{pt}=1.0 mm)

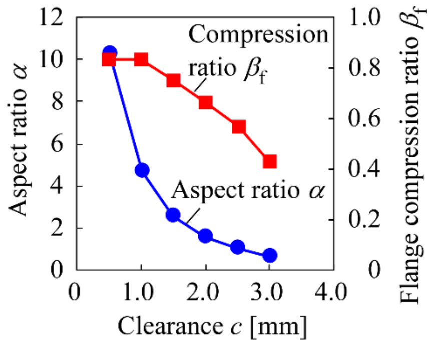


Figure 10: Aspect ratio and flange thickness variations with change in clearance (L_p=3.0 mm, R_{pt}=0.6 mm)

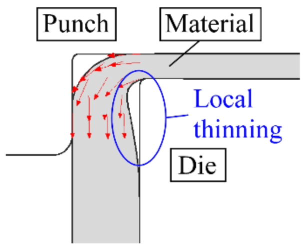


Figure 11: Thinning of side wall near flange (c=2.0 mm, L_p=3.0 mm, R_{pt}=0.6 mm)

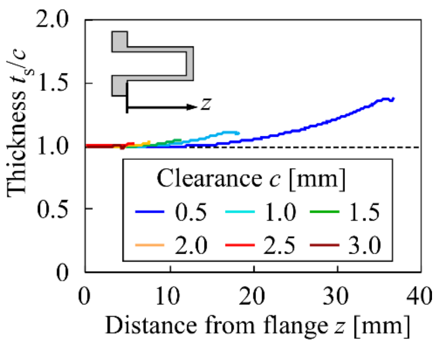


Figure 12: Effect of clearance c on side wall thickness distribution (L_p=3.0 mm, R_{pt}=0.6 mm, β_f=0.33)

defects. α increases by thinning of the side wall and large compression of the flange. When c was 0.5 and 1.0 mm, it was possible to compress the flange at the maximum compression ratio β_f=0.83, and maximum α is 10.2 under the condition of c=0.5 mm in this investigation.

When c was over 1.5 mm, local thinning occurred on the side wall near the flange when the flange thickness t_f was small compared to c as shown in Fig. 11. This defect occurs because the thickness of the material, which flows from the flange portion, becomes gradually thinner than c with the flange compression. Therefore, β_f should be controlled under a certain value with c in order to suppress this local thinning.

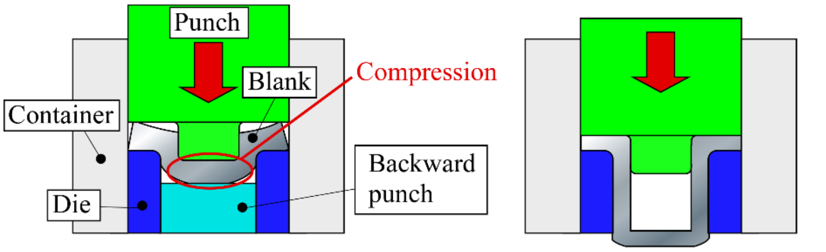
Figure 12 shows the side wall thickness distribution with the change of c. Thickness t_s/c increased with a decrease in c, because the clearance c_1 between the punch top corner and the die corner become large compared to c when c is small as shown in Fig. 9. Thus, it is possible to obtain the deep cup by decreasing c, although the dimensional accuracy is low.

4.4 Two-step process for improving the dimension accuracy

A two-step process was proposed in order to improve the dimensional accuracy of the formed cup as shown in Fig. 13. In first step, a fixed backward punch is used. The blank was stretched into the die with compression between the punch convex and the backward punch, as shown in Fig. 13 (a); this way, the local thinning at the punch top corner is suppressed by compression. After the first step, the backward punch was removed, and the flange was compressed as shown in Fig. 13 (b). Figure 14 shows the tool's position after the first step. Compression ratio of the thickness of the cup bottom portion β_b was controlled by changing the position of the backward punch, and β_b is calculated by the following expression.

$$\beta_b = \frac{t_0 - t_b}{t_0} \tag{3}$$

Here, t_0 is the initial blank thickness, and t_b is the bottom thickness of the cup as shown in Fig. 3. The punch convex length L_p was set at 3.8 mm as total length of the blank thickness t_0= 3.0 mm, the die corner radius R_d= 0.2 mm and the punch top corner radius R_{pt}= 0.6 mm for preventing the change of the clearance c_1 in Fig. 9 during the flange compression.



(a) First step (Initial stretching) (b) Second step (Compression)

Figure13: Schematic illustration of the two-step process

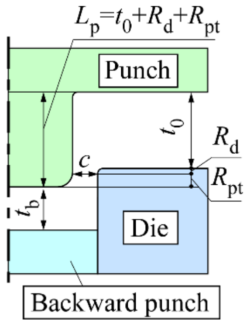
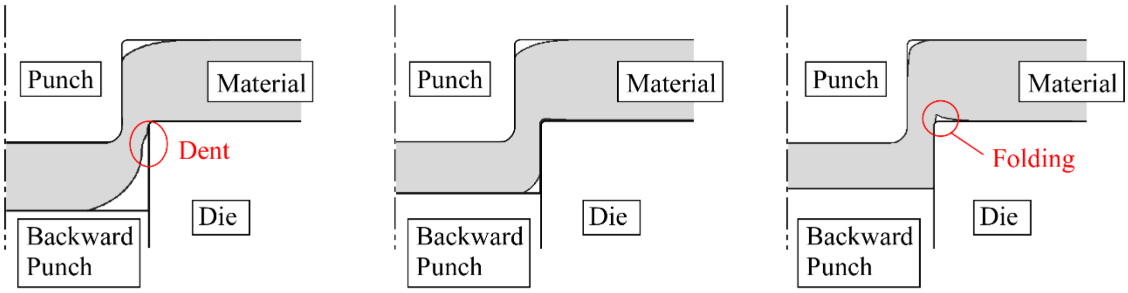


Figure 14: Tooling for the two-step process

At first, appropriate β_b was investigated. Figure 15 shows the appearance of the cup after the first step using the backward punch under the condition that the clearance c was 1.0 mm. The material was stretched without the local thinning when the compression amount β_b was appropriate as shown in Fig. 15 (b). The local thinning appeared when β_b was too small as shown in Fig. 15 (a). Folding appeared due to the material flow from the cup bottom when β_b was too large as shown in Fig. 15 (c). Table 2 shows the formability in the first step using backward punch. Appropriate range of the bottom compression ratio is narrow when the clearance c was small, because the local thinning is easy to occur during the first step.

Based on the above result, two-step process was conducted. Figure 16 shows the appearance of the formed cup by the two-step process using the backward punch, and Fig. 17 shows the side wall distribution compared with the one-step process without the backward punch. Appearance of the formed cup was ideal, and the side wall thickness was equal to c and completely uniform.



(b) β_b=0.17 (b) β_b=0.37 (c) β_b=0.43

Figure 15: Effect of bottom compression ratio β_b on the cup shape after first step (c=1.0 mm)

Table 2: Formability in first step using backward punch

Clearance c [mm]	Bottom compression ratio β_b						
	0.17	0.23	0.25	0.27	0.30	0.37	0.43
0.5		△	○	×			
1.0	△	○	○	○	○	○	×
○:Success △:Dent ×:Folding							

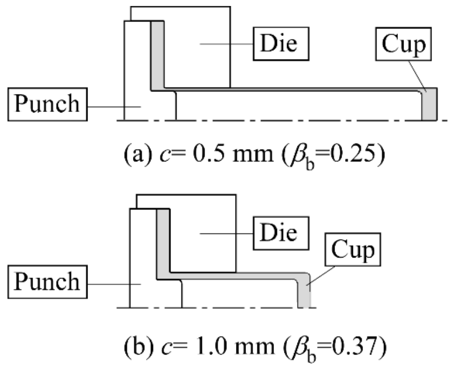


Figure 16: Appearance of the cup formed by two-step process (c=1.0 mm, L_p=3.8 mm, R_{pt}=0.6 mm, β_f=0.33)

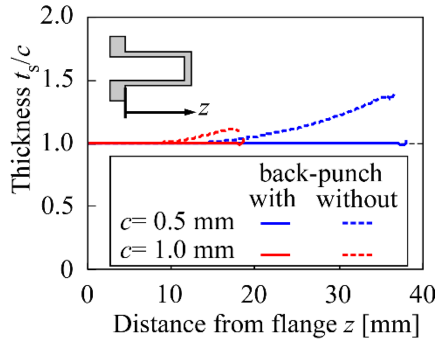


Figure 17: Side wall thickness distribution of the cup formed by one-step and two-step processes with backward punch (c=1.0 mm, L_p=3.8 mm, R_{pt}=0.6 mm, β_f=0.33)

5 CONCLUSIONS

- This paper presents a new deep drawing method that applies compressive force on the flange, and an investigation of the tool design was conducted using the FEM for improving the dimensional accuracy of the formed cups.
- The proposed method is composed of initial stretching and flange compression. The main tools are a punch with convex and a die.
- The punch convex length should be over the blank thickness for a cup with uniform side wall thickness.
- Local thinning is prevented by increasing the punch top corner radius, but side wall thickness becomes uneven when the punch top corner radius is too large.
- A deep cup could be obtained by decreasing the clearance between the punch convex and the die, and a maximum aspect ratio of 10.2 was obtained in this study. However, the dimensional accuracy decreases with a decrease in the clearance.
- A two-step process using a backward punch was proposed for the improvement of the dimensional accuracy when the clearance is small. A cup with uniform side wall thickness was successfully formed by the two-step process.

REFERENCES

[1] Doege, E., Hallfeld, T. Metal Working: Stretching of Sheets. *Encyclopedia of Materials: Science and Technology (Second Edition)* (2001): 5518-5521.

[2] Harada, Y., Maeda, Y., Ueyama, M. and Fukuda, I. Improvement of formability for multistage deep drawing of Ti-15V-3Cr-3Sn-3Al alloy sheet. *Procedia Engineering* (2014) **81**:819-824.

[3] Horikoshi, Y., Kuboki, T., Murata, M., Matsui, K., Tsubokura, M. Die design for deep drawing with high-pressured water jet utilizing computer fluid dynamics based on Reynolds' equation. *Journal of Materials Processing Technology* (2015) **218**: 99-106.

[4] Hatanaka, N., Waki, S., Iizuka, T. Deep drawing of square cup with airtight using developed blank of 1100 aluminum sheet. *Journal of The Japan Institute of Light Metals* (2014) **64**-8: 361-367. (in Japanese)

[5] Maslennikov, N.A. Russian developed punchless drawing. *Metalwork Production* (1957) **16**: 1417-1420.
[6] Hassan, M.A., Suenaga, N., Takakura, N., Yamaguchi, K. A novel process on friction aided deep drawing using tapered blank holder divided into four segments. *Journal of Materials Processing Technology* (2005) **159**: 418-425.
[7] Iizuka, T., Hatanaka, N., Takakura, N. Deep Drawing of High Cup of Magnesium Alloy AZ31 by Compressive Force, *Steel Research International* (2010) **81**-9: 1247-1250.