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Experimental Determination of the Optimum Blank Shape in Rectangular Cup Drawing

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ABSTRACT

The rectangular deep drawing process is widely used in sheet metal forming, but there are various associated defects, such as earing, wrinkling, tearing, etc. In order to avoid such defects, an optimum blank shape is required. Such an optimum blank shape cannot be generalized because deep drawing processes are involved in complex process parameters. So, it is necessary to do systematic research to determine the optimum blank shape for the deep drawing process. In this study, a rectangular cup drawing test has been carried out to determine the optimum blank shape for various stainless steel sheets. From the test, a new blank model, which has no earing, is propsed.

Keywords : Deep drawing, Stainless Steel, Blank Shape, Earing

1. Introduction

There are several aspects related to maximum forming depth in the rectangular deep drawing process. Formability of the material, outline radius of the punch and the die, lubrication conditions, processing speed, the pressurization method of the blank holding force, clearance and other process conditions must all be considered. In particular, the shape of the blank causes most effect because it determines the contact surface of blank with blank holder, die, etc. The blank holding force and forming load increase as the contact surface increases. And these can also cause the loss of material through trimming which is currently the most difficult problem in rectangular cup drawing.

To resolve such problems, much research on blank shapes used in rectangular cup drawing has been undertaken. Some recent research has been done based on membrane theory, but the data provide only limited help [2-4]. The blank shape obtained from such theoretical research doesn't provide a geometrical standard, but only an approximate shape for the blank. The purpose of this research is to gather data for the blank process, through experiments, to determine optimum blank shape.

2. Experiment

2.1 Blank Materials

The five stainless steels used in these experiments are widely used in appliances and kitchenwares. Table 1 illustrates the five stainless steels selected for blank materials and their properties. STS304BB (0.5mm) is used to determine the optimum blank shape, and four other materials are used to confirm the applicability of the optimum blank shape for different thicknesses.

Table 1 Stainless steel sheets used in the experiment

	Thickness (mm)	Yield Strength (kgf/mm^2)		
		0°	45°	90°
STS304BA	0.5	28.21	28.74	27.54
STS304BB	0.5			
STS430BA	0.7	35.82	37.53	28.71
STS434BB	1.2	35.08	25.93	36.04
STS434J1L	1.2	29.61	30.48	31.25

2.2 Experimental procedure

The die was equipped to a 50ton-hydraulic press and blank holding force was applied using four nitrogen springs. The forming load and forming depth were measured by installing a load-cell (maximum capacity of 20tons) and an LVDT (maximum measurement length of 100mm). Fig. 1 shows a schematic diagram of the deep drawing (die) setup.

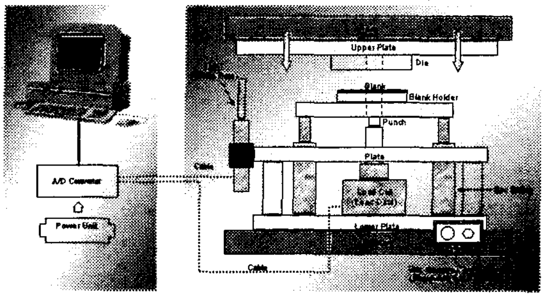


Fig. 1 Schematic diagram of the deep drawing setup

2.3 Experimental conditions

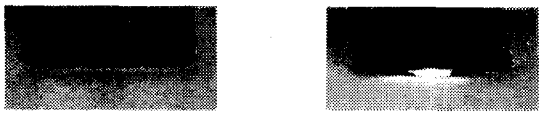
The conditions for the deep drawing test are the same in Table 2. Conditions were set through experiments regarding die material and clearance, and blank holding force and product shape were selected based on Kobayashi's and others' [1] research results. Also, WD40 was used as a lubricant.

Table 2 Experimental conditions

Tool Material	STD11(TD coating)
Clearance	20% of sheet thickness
Product Size(mm)	40*40*(height)
Die Radius(straight line)	6mm
Die Radius(corner)	6mm
Punch Radius	6mm
Blank Holding Force	1000kgf
Lubricant	WD40

2.4 Optimum blank shape

The procedure for determining optimum blank shape is already known through previously experimental studies. However, when the previously proposed blank is used, there will be almost no earing at a low drawing rate. But, if the rate is high, the earing is very severe, as shown in Fig. 2. So, a blank shape that does not create earing at a high drawing rate is needed. The theoretical optimum blank shape proposed through the finite element method provides only approximate shape, and does not provide a geometrical calculation that can be generally applied.



(a) Low Drawing Ratio (a) High Drawing Ratio

Fig. 2 The results using the previously proposed blank shape

In this research, the optimum blank shape was determined by circular and octagonal blank standards, through trial and error and with reference to Kobayashi[1]. The various blank shapes used in the experiment are illustrated in Fig. 3.

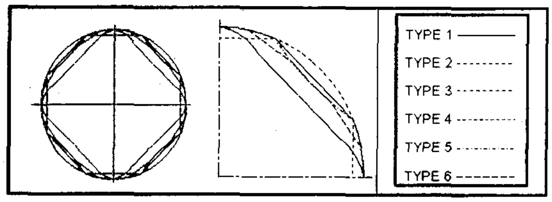


Fig. 3 Various blank shapes used in the experiment

The six blanks illustrated in Fig. 3 are as follows:

a) type 1 : blank proposed through a previous experiment
b) type 2 : circular blank
c) type 3 : right octagonal blank inscribed within type 2
d) type 4 : blank formed by pushing outwards on four edges that aren't touching each other in type 3 in a circular shape (The radius is the same as in type 2)
e) type 5 : blank formed by pushing other four edges inward in type 4 (The diameter is the same as in type 2)

f) type 6 : blank that connects quarter(1/4) points of in-and-out line of blank type 5

3. Experimental results and discussion

After doing the experiment on the shapes proposed in Fig. 3, the load-displacement curves for those shapes were determined, as shown in Fig. 4.

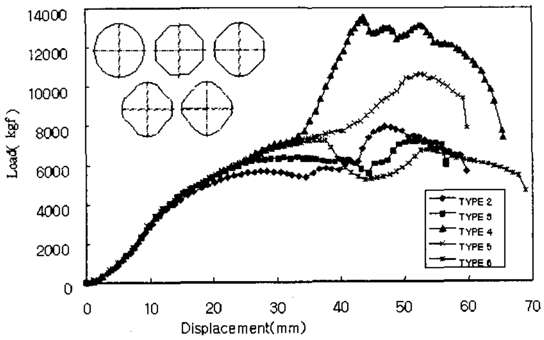


Fig. 4 Load-displacement curves for various blank shapes

According to Fig. 4, types 4 and 5 showed a sudden increase of load due to wrinkles. Type 6 had the largest forming depth without earing among all six blank shapes. The variation of earing shape according to blank shape is shown in Fig. 5.

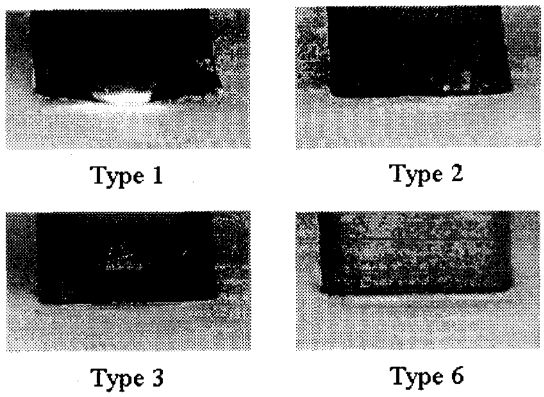


Fig. 5 Variation of earing shape according to blank shape

Type 1 lacks materials at corners, types 2 & 3 show earing and types 4 & 5 show extreme ironing due to wrinkles, which caused fracture. As we know through Figs. 4 & 5, considering the maximum forming load, maximum forming depth, and earing size, we can determine that type 6 is the optimum blank shape.

In Fig. 6, a selected optimum shape (□) is compared with the blank shape that is currently used (△), the blank shape proposed by Kobayashi and others (0) [1], and the blank shape proposed by Kuwabara and others (×) [3].

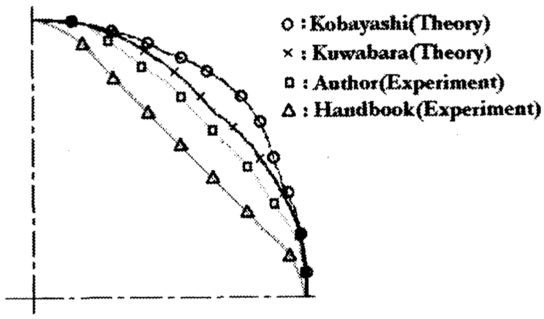


Fig. 6 Comparison of the blank shape for rectangular deep drawing

Except for Kobayashi's blank, all the other blanks' corners are indented inwardly. In the case of type 1 blank, there is a lack of materials at the corners. Conversely, Kobayashi's blank has extra materials at the corners, which causes earing [1]. Only Kuwabara's blank matches the results of the experiment.

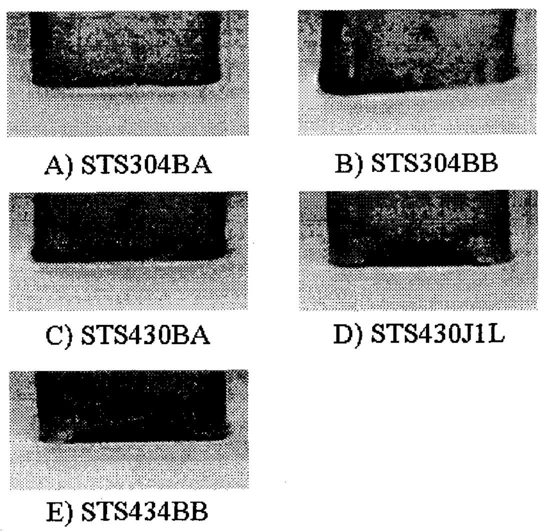


Fig. 7 Earing shapes for various stainless steel sheets

The results of applying optimum blank shapes to other stainless steels, with different properties, thicknesses, and shapes, are shown in Fig. 7. The ear height is very low when it is applied to stainless steels of different types, with different thicknesses and properties. Therefore, type 6 can be determined to be the optimum blank shape for stainless steel.

4. Conclusion

In this study, an optimum blank shape was determined as one that does not cause earing. The results of the research, which determine the optimum blank shape for stainless steel through rectangular cup drawing experiments, are as follows.

1) The previously used blank shape is different from the experimental shape in regard to deep forming.
2) The optimum blank shape determined by the experiment has inwardly indented corners and outwardly indented straight-line areas.
3) When compared with theoretical optimum blank shape, the results were good.
4) By determining the optimum blank shape, the loss of material due to trimming can be minimized. The reduction of forming load and the increase of maximum forming limit are also possible.

References

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