Drawability of Functional Corrugate Cup Using Roller Die

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The formability of the corrugated cup was investigated by the deep drawing process. Deep drawing, which is one of press forming, is a plastic processing technology for forming a thin plate into a three-dimensional container or case. For container products, there are many products formed by this technology. Depending on the application, the functionality of the container itself was required. For example, there are embossing, thickening, and tailored blanks processing. In the present study, corrugated cup was formed to enhance the functionality of the cup. A unique die was used to form the cup having a corrugated shape. The shoulders of the die were grooved, and the steel balls were arranged without gaps in the groove. The balls rotated freely during forming. In an experiment, the blanks were commercially extra-low carbon steel SPCC and stainless steel SUS304. The initial diameter and thickness of the blank were 70 to 95 mm and 0.3 to 0.5 mm. The lubricant was the solid powders of molybdenum disulfide. The deep drawing process was performed using an oil hydraulic press at a forming speed of approximately 10 mm/min. The diameter of the punch was 40 mm, and the smallest hole diameter of the die was 41 mm. These tools were tool steel SKD11, and were standard heat treated. The metal sheets were successfully drawn without the cracks. In the side wall of the cup, the distance between the waves was approximately 8.6 mm. The thickness strain at the bottom of the drawn cup SPCC was no more than 0.1.

Keywords: sheet forming, deep drawing, formability, corrugated cup, ultralow-carbon steel, stainless steel

1. Introduction

Press working is a technology to process metal using two metal dies, upper die and lower die. This technology is suitable for processing mass-produced products because it is possible to mass-produce the same products. Deep drawing, one of the press processes, is a technology to form a seamless hollow three-dimensional container using a blank cut from a metal plate. In this processing method, a wide variety of products are used in industry. There are industrial products such as automobile parts and motor cases, and household goods such as aluminum cans. As described above, deeply drawn containers are used in various fields, so there is a need to improve the functionality of the containers themselves. As a processing example of functional improvement, there are embossing, thickening, and tailored blanks processing. Many investigations have been made of the processing on the functional containers. The superplastic micro-forming method with a fine grained Zn–22Al eutectoid alloy using hot embossing technology was reported.1) The effects of embossing and restoration process on the deep drawability of aluminum alloy sheets were reported.2) A multi-stage stamping including thickening of corners of drawn part thickening of two corners was carried out.3) Deep drawing of tailored blanks without a blankholder was investigated.4) In addition, many studies by the forming simulation analysis method were reported.5,6) However, at present there are few technologies for improving the functionality of cups. On the other hand, the authors examined the formability of the clad cup using different metal sheets. The clad sheet metals are increasingly used in the field of production and processing, because of their excellent mechanical and functional properties. The bauschinger effect on springback of clad sheet metals in draw bending was reported.7) In our research, the clad cup was formed by deep drawing with thin sheets of dissimilar metals stacked. The formability of pure titanium clad sheet by multistage deep drawing was also investigated to enhance corrosion resistance of steel cup.8) In the present study, it was attempted to form the corrugated cup with the wavy shape on the side wall of the cup. In order to shape the side wall of the cup into a corrugated shape, deep drawing of the cup was performed by placing steel balls on the shoulder of the die. In the drawn cup, the shape, thickness strain, and hardness were examined respectively.

2. Experimental Procedure

2.1 Materials

The blank for deep drawing was cut from cold rolled steel sheet by shearing and blanking. The steel sheet was an ultralow-carbon steel, JIS-SPCC. Austenitic stainless steel, JIS-SUS304 was also used. Austenitic steel is the most widely used grade of stainless steel due to its excellent formability and corrosion resistance. The initial diameter and thickness of the blank were 70 to 95 mm and 0.3 to 0.5 mm. The die and punch were cold-work tool steel JIS-SKD11. They were heat treated under standard conditions.

2.2 Deep drawing

The deep drawing process was performed using an oil hydraulic press at a forming speed of approximately 10 mm/min. Figure 1 shows the schematic illustration of deep drawing (a) and actual appearance of the produced roller die (b). The groove was machined at the shoulders of the die. To deform the side wall of the cup into a wave shape, steel balls were placed in the groove without the gap. The steel balls were rotated during drawing. Steel ball was bearing steel, the diameter was 10 mm. The clearance between the punch and die was set to be equal to the thickness of the sheet. A punch diameter was 40 mm, and the drawing ratio was 1.67. A shoulder radius of punch was 3 mm. The lubricant was the
solid powders of molybdenum disulfide (ThreeBond 1910 type, specific gravity: 1.6, viscosity: 1.6 Pa-s). The forming conditions of deep drawing are shown in Table 1.

### 2.3 Measurement of thickness strain and hardness

The thickness of the drawn cup was measured from the center of the bottom of the cup to the side wall using a digital micrometer (Digimatic outside micrometer type, by Mitutoyo Corporation). In the rolled sheets, it is known that anisotropy is caused by a crystalline structure. In order to investigate the influence of anisotropy on the thickness strain, strain distribution in three directions was measured. The directions are 0, 45, and 90 degrees to the rolling direction (RD).

Vickers hardness test was also performed to measure hardness of the drawn cup after deep drawing. The measuring instrument used was the micro Vickers hardness tester (by Akashi Seisakusho, Ltd.). The hardness of the drawn cup was measured from the center of the bottom of the cup to the side wall. The hardness value was calculated by averaging seven or more measurements.

### 3. Results and Discussions

#### 3.1 Visual appearance of drawn cup

The effect of the blank diameter on the formability was investigated. The appearances of the drawn cups after deep drawing using the blank of 70 to 95 mm in diameter are shown in Fig. 2. The sheets were the ultralow-carbon steel SPCC. In cups formed from the blank diameter of 70 to 90 mm, no cracking or breakage of the cup was seen at all. It can be seen that the formability is a sufficient shape. The distance between the convex portions on the side wall of the cup was approximately 8.5 mm. On the other hand, the drawn cup formed from the blank diameter of 95 mm was broken at the bottom corner area. The forming limit was found to be approximately 2.2. This value was approximately equal to the value in the conventional drawing.

In order to investigate the formability of an iron alloy sheet having corrosion resistance, the deep drawing was examined using the stainless steel sheet. The effects of the blank diameter and the thickness on the formability were investigated. The appearances of the drawn cups after deep drawing using the blank of 70 to 85 mm in diameter are shown in Fig. 3. There are three types of thickness, 0.3, 0.4, 0.5 mm. In deep drawing using the stainless steel sheets, the drawn cups were excellent in formability. Almost no influence of sheet thickness on formability was observed.

#### 3.2 Height of drawn cup

In order to measure the shape of the drawn cup, the height of the cup was examined. Figure 4 shows the variation of height of the drawn cups with diameter of blank (a), and the appearances of the conventional cups (b). In Fig. 4(a), the values obtained by the conventional drawing are also shown. The height of the corrugated cup was lower than that of the conventional cup. It was approximately 8% lower. Since the side wall of the drawn cup was corrugated, the circum-

| Fold pressure | 5 - 10 kN |
|---------------|-----------|
| **Die**       | **Material** | SKD11 |
|               | **Diameter** | 41 mm |
| **Steel ball bearing** | **Material** | SUJ2 |
|               | **Diameter** | 10 mm |
|               | **Hardness** | 800 HV |
| **Punch**     | **Material** | SKD11 |
|               | **Diameter** | 40 mm |
|               | **Corner radius** | 3 mm |
| **Clearance** | 0.5 mm |
| **Lubricant** | Molybdenum disulfide type |
The differential length of the cup was long. In other words, the area of the side wall area was increased. Next, deep drawing was performed using the stainless steel sheet. The diameter and thickness of the blank were 85 mm and 0.5 mm. Similar to the results obtained with the SPCC cups, the height of the corrugated cup was lower than that of the conventional cup (Fig. 5).

### 3.3 Vickers hardness

The steel sheet after plastic deformation is work-hardened. Therefore, the hardness of the drawn cup after forming was examined. Figure 6 shows the hardness distribution at the side wall of the drawn cup (a), and the schematic view of the measurement position (b). The blank was the carbon steel SPCC. The hardness measurement position was half the height of the drawn cup. The hardness distribution was in the circumferential direction of the side wall of the drawn cup. The diameter and thickness of the blank were 85 mm and 0.5 mm. The hardness value was higher at the convex part of the draw cup. This is because the thin sheet was bent by buckling in the gap between the steel balls. Namely, the material flows into the gaps between the steel balls, and the sheet deforms to the shape of the convex. In the circumferential direction, buckling was likely to occur because compressive stress was applied during deformation. The drawn cup was work hardened compared to the hardness of the blank. However, the hardness of the convex part was about the same as compared to the hardness of the conventional drawn cup.

### 3.4 Thickness strain

After the cold deep drawing, it is well known that the thickness distribution of formed cups is uneven. Namely, the thickness of the wall at the bottom corner tends to decrease, whereas the thickness at the opening tends to increase. The distribution of the thickness strain of the drawn cup SPCC was investigated. Figure 7 shows the distribution of wall
thickness strain of the drawn cup by deep drawing. In order to investigate the effect of anisotropy on the formability, the strain distribution was measured in three directions of 0 degree, 45 degrees, and 90 degrees. A standard position of the measurement was the center of the bottom of the drawn cup. Thickness strain was measured from the bottom of the cup to the opening. The thickness increases from the bottom of the drawn cup to the opening. The reduction of sheet thickness of corner parts where the thickness strain was small was no more than 0.1. This value was close to the value obtained in a conventional drawn cup. Almost no influence of anisotropy on formability was observed. It turned out that it could be used as the drawn cup.

In addition, the distribution of the thickness strain of the drawn cup SUS304 was investigated. Figure 8 shows the distribution of wall thickness strain of the drawn cup. Similar to the results obtained with the drawn cups SPCC (Fig. 7), the thickness increased from the bottom of the cup to the opening. Compared with the thickness change of the drawn cup SPCC, that of the drawn cup SUS304 was larger. It is assumed that the elastic modulus of stainless steel is slightly smaller than that of the ultralow-carbon steel. The reduction of sheet thickness of corner parts where the thickness strain was small was no more than 0.05. The effect of the sheet thickness on the diameter of the drawn cup SUS304 was investigated. The variation of the diameter of the drawn cup with distance from bottom of cup is shown in Fig. 9. The clearance between the steel balls and the punch was 0.5 mm. When the thickness of the blank decreases, the change in diameter of the drawn cup hardly changes. There is almost no effect of the sheet thickness on the diameter of the drawn cup.

4. Conclusions

The formability of the corrugated cup was investigated by the deep drawing process. By placing the steel balls on the shoulder of the die, it was tried to form the deep-drawn cup with a corrugate shape on the side wall of the cup. The obtained findings are shown below.

(1) By arranging the steel balls on the shoulders of the die, it was possible to form the cup having an uneven shape on the side wall of the cup.

(2) When the blank diameter was in the range of 70 to 90 mm, the drawn cup did not crack at the bottom or at the wall. It was found that the formability of the drawn cup was sufficient.

(3) The distance between the projection tip on the side wall was approximately 8.6 mm.
Fig. 7 Distributions of thickness strain of corrugated cup SPCC. (a) 0 degree to RD (b) 45 degrees to RD (c) 90 degrees to RD.

Fig. 8 Distributions of thickness strain of corrugated cup SUS304. (a) 0 degree to RD (b) 45 degrees to RD (c) 90 degrees to RD.
The maximum reduction in the thickness was at the bottom corner of the drawn cup. However, the decrease ratio of the drawn cup SUS304 was less than approximately 5%.

(5) It was found that there was a possibility of improving the heat dissipation and strength of the cup.

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