Improvement of formability in ironing of stainless steel drawn cups using low friction cermet dies

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Abstract

A TiCN-based cermet die was utilised to improve the formability in ironing of stainless steel drawn cups. By employing the cermet die, additional coating was not required because it was made of hard TiCN having low friction. As a comparison, TiC-coated WC-Co, non-coated WC-Co and tool steel dies were used. The effects of the viscosity of a lubricant and the ironing speed on the formability for the cermet die were examined. The cermet die exhibited the largest seizure resistance. The performance of the cermet die in repeated ironing was evaluated. For repeated ironing using the cermet die, the occurrence of seizure was prevented up to 100 strokes. It was found that the cermet die with low friction was effective in ironing stainless steel drawn cups.

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1. Introduction

The production of batteries used for electric and hybrid cars increases, and battery cases are mainly produced by deep drawing and ironing of stainless steel and aluminium alloy sheets. In ironing of stainless steel drawn cups, the
fracture and seizure tend to occur. The fracture limit in ironing is affected by the friction between a cup and die (Delarbre et al., 1999).

Bay et al. (2010) reviewed lubrication mechanisms in ironing of sheet metal forming processes. To prevent the occurrence of seizure, lubricant is conventionally used in ironing. Kawai et al. (1992) showed that the seizure was prevented by appropriate viscosity of lubricants in ironing of aluminium cups. Ironing operations in the stainless steel cups are severe due to high flow stress and low thermal conductivity, and thus low friction coating of dies by the CVD and PVD treatments is generally used. The TiCN, AlTiN and CrN PVD coatings showed high anti-adhesion performance for deep drawing of high strength steel (Sresomroeng et al., 2010). Although wear resistance of the coating is desirable to improve the die life, the wear resistance of the coating by PVD and CVD is not enough.

Since the tool wear in deep drawing and ironing is problematic in the mass production, low friction tool materials such as ceramics and cermets are applied. For deep drawing of stainless steel using an alumina ceramic die, the drawing load was significantly reduced (Kataoka et al., 2004). Tamaoki et al. (2010) proposed the electroconductive ceramic die for deep drawing, and the cups were successfully deep drawn over 10,000 times (Tamaoki et al., 2013). However, it is not easy to apply the brittle ceramic die to ironing of stainless steel cups. A TiCN-based cermet becomes more attractive for cutting tools because the cermet has excellent wear resistance (Fu et al., 2008; Chen et al., 2008). Therefore, the TiCN-based cermet is expected to be effective for improving the formability in ironing of stainless steel drawn cups.

In the present study, a TiCN-based cermet die was utilized to improve the formability in ironing of stainless steel drawn cups. For a comparison, TiC-coated WC-Co, non-coated WC-Co and tool steel dies were employed. The effects of viscosity of a lubricant and ironing speed on the formability of the cermet die were examined. The performance of the cermet die in repeated ironing was evaluated.

### Nomenclature

| Symbol | Description                        |
|--------|------------------------------------|
| \( c \) | clearance between die and punch    |
| \( d_p \) | punch diameter                     |
| \( r \) | ironing ratio                      |
| \( t_0 \) | initial thickness of blank         |
| \( t_m \) | average of wall thickness of ironed cup |
| \( v \) | ironing speed                      |
| \( z \) | distance from bottom of ironed cup |
| \( \rho \) | kinematic viscosity of lubricant    |

### 2. Ironing conditions

The ironing conditions of the stainless steel cups produced by deep drawing are shown in Fig. 1. The ironing experiment was performed by using a universal testing machine with an ironing speed \( v = 8.0 \text{ mm/s} \). The outer diameter and height of the drawn cup were between 34.3 and 34.5 mm and between 25.4 and 25.9 mm, respectively. The ironing limit is defined by the ironing ratio which no seizure and fracture occur on the die and the cup surfaces. The ironing ratio is given by

\[
r = \frac{t_0 - t_m}{t_0},
\]

where \( t_0 \) is the initial thickness of a blank and \( t_m \) is the average of the wall thickness of the ironed cup. To change the ironing ratio, the clearance \( c \) between the die and punch is changed by the punch diameter \( d_p \) while the inside diameter of the die is fixed at 34 mm. The mechanical properties of the austenitic SUS304 and ferritic SUS430 stainless steel sheets having 0.6 mm in thickness are shown in Table 1. Before ironing, a liquid lubricant
containing a chlorine additive was applied to the die and cup. For the SUS304 cup, the lubricant with the kinematic viscosity \( \rho = 513 \text{ mm}^2/\text{s} \) at 40 °C was employed. For the SUS430 cup, the lubricants with the kinematic viscosity \( \rho = 513 \) and 3.0 mm\(^2\)/s at 40 °C were applied.

| Lubricant | Drawn cup | Punch (SKD11) | Die | Ring |
|-----------|-----------|---------------|-----|------|
|           |           |               |     |      |

Fig. 1. Ironing conditions of stainless steel cup.

Table 1. Mechanical properties of stainless steel sheets.

| Sheet   | Tensile strength [MPa] | Elongation [%] | \( n \)-value | \( r \)-value |
|---------|------------------------|----------------|------------|-------------|
| SUS304  | 710                    | 59.3           | 0.40       | 1.01        |
| SUS430  | 547                    | 25.7           | 0.20       | 1.17        |

The surface of the die land made of the different tool materials is shown in Fig. 2. The dies made of the tool steel SKD11, non-coated WC-Co, CVD-coated WC-Co with TiC coating and TiCN-based cermet were utilised. The WC-Co is a V20 code in accordance with JIS B 4053. The TiCN-based cermet with a nickel binder was produced by sintering. Because the main component of the cermet is made of the low friction TiCN, an additional surface coating is not required. The surface roughness and the Vickers hardness of the dies are shown in Table 2. All the die surfaces were finished by lapping hence their surfaces are very fine with surface roughness in an axial direction about 0.02 \( \mu \text{mRa} \). The maximum hardness was obtained from the TiC-coated WC-Co die, while the tool steel die exhibits minimum hardness.

Table 2. Surface roughness and Vickers hardness of dies.

| Die material          | Surface roughness in die land | Vickers hardness [HV] |
|-----------------------|-------------------------------|-----------------------|
|                       | Arithmetic mean [\( \mu \text{mRa} \)] | Maximum height [\( \mu \text{mRz} \)] | |
| Tool steel SKD11      | 0.02                          | 0.28                  | 750       |
| Non-coated WC-Co V20  | 0.02                          | 0.21                  | 1650      |
| TiC-coated WC-Co V20  | 0.02                          | 0.14                  | 1650, 3000 (TiC) |
| TiCN-based cermet     | 0.02                          | 0.20                  | 1550      |

3. Ironing results

3.1. Ironing limit of SUS304 stainless steel

The SUS304 ironed cups with the non-coated WC-Co die are shown in Fig. 3. At \( r = 11\% \) no defect occurs on the surface of the ironed cup. When the ironing ratio is increased to \( r = 15\% \) and \( 21\% \), the seizure and the fracture take place, respectively.

The wall thickness distribution in the side wall of the ironed cups for SUS304 with the different tool materials and \( d_p = 33.16 \text{ mm} \) is shown in Fig. 4. The wall thickness was measured every 3 mm by starting at 6 to 30 mm...
from the bottom of the ironed cup. Using the tool steel die shows the largest wall thickness of the ironed cup because of the large elastic deformation of the die. The wall thickness becomes thin with the TiCN-based cermet, TiC-coated WC-Co and non-coated WC-Co dies, respectively. The thinner portion of the wall thickness of the ironed cups is located near the bottom which corresponds to the position of the fracture as shown in Fig. 3(d).

Fig. 3. SUS304 ironed cups with non-coated WC-Co die.

Fig. 4. Wall thickness distribution in side wall of ironed cups for SUS304 with different tool materials and $d_p = 33.16$ mm.

The ironing limit, the surface of the die land and the ironed cups for SUS304 with the different tool materials are shown in Fig. 5. For the tool steel die, the seizure occurs early on the die surface. By employing the non-coated WC-Co, TiC-coated WC-Co and TiCN-based cermet dies, the ironing limit is improved. The TiCN-based cermet die exhibits the largest seizure resistance, and then no seizure is observed on the surfaces of the die and cup sidewall.

Fig. 5. Ironing limit, surface of die land and ironed cups for SUS304 with different tool materials.
3.2. Ironing limit of SUS430 stainless steel and effect of viscosity of lubricant

The ironing limit and the surface of the die land for the SUS430 cup with the different tool materials are shown in Fig. 6. By applying the lubricant having viscosity $\rho = 3.0 \text{ mm}^2/\text{s}$, the ironing limit of each die is slightly different. By applying lubricant having viscosity $\rho = 513 \text{ mm}^2/\text{s}$, the ironing limit of all dies except the tool steel die is significantly improved. The seizure does not occur at $r = 20\%$. Since the cermet die shows high seizure resistance, this die was chosen for the investigation of an effect of the ironing speed.

![Fig. 6. Ironing limit and surface of die land for SUS430 cup with different tool materials.](image)

3.3. Effect of ironing speed on ironing limit of cermet die

The effect of the ironing speed on the ironing limit for stainless steel cups with the TiCN-based cermet die is shown in Fig. 7. In addition, the distribution of the temperature on the side wall of the ironed cup is also illustrated. The distribution of the temperature was measured by a thermographic camera at 0.1 s after ironing. The upper portion of the SUS304 ironed cup at an ironing speed of 50 mm/s shows the high temperature. By increasing the ironing speed to $v = 50 \text{ mm/s}$, the ironing limit for both SUS304 and SUS430 is not improved. For SUS304 the fractures take place at near $r = 20\%$. For SUS430 at $r = 21\%$, $v = 25 \text{ and } 50 \text{ mm/s}$ the seizure and the delayed fracture occur.

![Fig. 7. Effect of ironing speed on ironing limit for stainless steel cups with TiCN-based cermet die.](image)

4. Performance of cermet die in repeated ironing of SUS430 stainless steel cups

The performance of the cermet die in repeated ironing of SUS430 stainless steel cups was evaluated until 100 strokes without polishing of the die surface. For a comparison, the TiC-coated WC-Co die was used. The blank was deep drawn and ironed in the same stroke with the ironing ratio about $r = 6\%$. The chlorine containing
lubricant having viscosity \( \eta = 3.0 \text{ mm}^2/\text{s} \) and an ironing speed of 75 mm/s were employed. The lubricant was applied to the die and blank surfaces. Because the blanks were manually fed into the die, the stroke per minute of the process was about 5 spm.

The ironed cups, the surface of the die land and the variation of the surface roughness in the side wall of the ironed cup for SUS430 in repeated ironing are shown in Fig. 8. Using the TiCN-based cermet die, the SUS430 cups were successfully formed until 100 strokes without the occurrence of seizure both on the cup and the die surfaces, whereas using the TiC-coated WC-Co die, the seizure takes place. Although surface roughness of the cups produced by the TiC-coated WC-Co die has a tendency to increase after 70 strokes, the roughness of the cups produced by the TiCN-based cermet die remains almost constant up to 100 strokes.

5. Conclusions

The TiCN-based cermet die was utilised to improve the formability in ironing of stainless steel drawn cups. The formability was effectively improved by employing the cermet dies. When the viscosity of the lubricant becomes large, the formability for the cermet and WC-Co dies was enhanced. By increasing the ironing speed, the formability of the TiCN-based cermet die was not increased. For repeated ironing using the TiCN-based cermet die, the SUS430 cups were successfully formed up to 100 strokes without the occurrence of the seizure both on the cup and the die surfaces.

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