Influence of Punch Shape on Drawability of Local Solution Treated 6061 Al Alloy Sheets

T. Nishiwaki¹, N. Kanetake²

¹ Nagoya Municipal Industrial Research Institute, 3-4-41,Rokuban, Atsuta-ku, Nagoya, 456-0058 JAPAN ² Nagoya University, Furo-cho, Chigusa-ku, Nagoya, 464-8603 JAPAN

Keywords: deep drawing, local solution, aluminum alloy sheet

Abstract

Deep drawing of strength graded blanks was investigated to improve the drawability of A6061 sheets. To soften outside part of drawing blanks, a local solution method was developed, in which the blanks were locally solution treated by the partial heating between heated dies. Deep drawing was carried out using cylindrical flat and hemispherical punches. The limiting drawing ratio of the strength graded blanks was 0.4-0.6 higher than that of uniform strength blanks for both punches. The optimal softening region for the hemispherical punch was larger than that for the flat punch. A numerical analysis was carried out to optimize the contacted softening region.

1. Introduction

The deep drawing of strength graded blanks has been investigated to improve the drawability of aluminum sheets. In this method, the center part of the blank has to be strengthened to avoid the fracture at a punch radius or a outer part has to be softened to draw in easily. The periphery annealing method [1], the periphery over aging method [2], and the center aging method [2,3,4] have been already examined to realize strength graded blank. Recently the method combined with laser heat treatment was also proposed [5]. In these researches, deep drawing tests were examined with only cylindrical flat punches, but practical industrial parts are more complicatedly formed with deep drawing and stretch forming.

In the present work, the drawability of a strength graded blank by local solution treatment was investigated for 6061 AI alloy sheet. The local solution treatment was realized by giving temporary thermal gradient to the blank with the heat contact between a couple of heated dies. The deep drawing tests were carried out with both cylindrical flat and hemispherical punches. Numerical analysis is used to optimize the contacted region and also to simulate a limiting drawing ratio of the strength graded blanks.

2. Experimental Procedures

As a starting material, the 6061 aluminum alloy sheet (1.0mm thickness) was prepared in T6 heat treated condition.

A couple of ring shape heated dies made from SKD11 were used so that only a flange part of the drawing blank could be heated. The 4 couples of the heated dies shown in Table 1 were prepared and their sizes of upper and lower dies were the same.

Table 1: Dimensions of heated dies.						
Inner	Outer					
Diameter	Diameter					
39.6	90.0					
46.2	90.0					
52.8	90.0					
59.4	90.0					
	Dimensions of Inner Diameter 39.6 46.2 52.8 59.4					

Table 1. Dimensions of bested dies

At first, the effects of heating temperature and holding time on the softening were examined using strip specimens of 7mm in width. The aluminum strips were clamped between upper and lower dies heated to various temperatures and quickly removed and quenched in water after different holding times. The sheet was clamped with a load of about 30 kN between heated dies and the time lag after unloading to quenching was around 1.6 sec.

The cylindrical deep drawing tests were conducted with tools shown in Table 2. A flat punch and a hemispherical punch were used in the tests. Blank hold forces are 2 kN, punch speed is 72 mm/min and a commercial press lubrication oil (a dynamic coefficient of viscosity; 53.3 mm²/s) was used. The local solution treatment of the blank was performed under the condition of heating temperature at 500 °C and holding time for 0.6sec. Uniform strength blanks, T6 and solution treatment (ST) sheets are also drawn as a comparison.

Table 2: Dimensions of	Drawing Die and Punch.
------------------------	------------------------

Punch	Diameter	33.0	
	Profile radius	5,16.5	
Die	Diameter	36.2	
	Profile radius	5	



3. Experimental Results

Figure 1: Softening of 6061 Al alloy sheets contacted with heated dies.

The Vickers hardness after some heat treatment conditions to determine the local solution conditions is shown in Figure 1. The softening, decrease in hardness, is saturated with heat treatment above 450 °C in any holding time. It was also confirmed that the decreased

789

hardness of the specimens heated above 450 $^\circ\!C$ could be recovered to that of the initial T6 sheet after artificial aging at 160 $^\circ\!C$ for 18 hours.

Distributions of Vickers hardness in the local solution treated blanks are shown in Figure 2. The regions contacted with heated dies of the blank are softened to the value of solution treated sheet. The non-contact part is also influenced by heat conduction from contacted regions and its hardness is lower than the T6 condition.



Figure 2: Distributions of Vickers hardness in local solution treated blanks.

The results of the deep drawing test with a flat punch are shown in Figure 3(a). The limiting drawing ratios of the local solution treated blanks were clearly increased from a value of 2.00 in uniform T6 or solution treated blanks. The blank treated with LST1.6 dies reached the limit at the 2.42 drawing ratio, that is 0.42 larger than that of uniform strength blanks. The blank treated with LST1.2 and 1.4 dies failed due to wall fracture and the blank with LST1.6 and 1.8 dies failed due to the punch profile radii fracture at the limit of drawing.



Figure 3: Experimental results of deep drawing with (a) a flat punch and (b) a hemispherical punch.

The results of the deep drawing test with a hemispherical punch are shown in Figure 3(b). The limiting drawing ratios of the local solution treated blanks were increased from value of 1.82 in uniform T6 blanks. The blank treated with LST1.4 dies reached more than 2.42 drawing ratio, that is 0.60 larger than that of uniform T6 blanks. The blank treated with LST1.2 dies failed due to wall fracture and the blank with LST1.6 and 1.8 dies failed due to the punch profile radii fracture at the limit of drawing.

In the results with a hemispherical punch, optimal softened region was larger than that with a flat punch. The limiting drawing ratios in the case of both punches are 2.42.



Figure 4: Failure types of local solution treated sheets with a hemispherical punch, (a) Success with LST1.4, D.R.=2.42, (b) Wall failure with LST1.2, D.R.=2.42, (c) Punch radii failure with LST1.6, D.R.=2.18, (d) Punch radii failure with LST1.8, D.R.=1.82.

4. Deep Drawing Analysis

In order to examine the optimal heat treatment region for improvement of drawability, a deep drawing analysis of the strength graded blank was performed. The LS-DYNA finite element method (FEM) explicit solver was used to analyze deep drawing. Drawing tools and a drawn blank were modeled as rigid-plastic materials respectively. In the strength graded blank the solution treated (ST) and the T6 treated material data were used for the outside soft part and the center hard part respectively. The transient part between the both soft and hard parts was not taken into consideration, namely the strength graded blank consisted of only soft and hard parts whose boundary was the same as the inner diameter of the heated die. The heated die sizes are shown in Table 2, which are the same as the experiment. The material data of ST and T6 treated 6061 aluminum alloy sheet were approximated with the equation of $\sigma = F \varepsilon^n$ from the stress-strain curves obtained by tensile tests. The parameters used for the analysis are shown in Table 3 together with the tensile test result.

	YS	TS	El	F-	n-
	(MPa	(MPa		value	value
))		(MPa)	
T6	304	334	13.8	431	0.07
ST	70	183	17.4	372	0.29

Table 3: Tensile properties and used parameters in analysis

The forming limit in the analysis was judged as the fracture with generating of a necking. The failure of local softening blanks occurred with two types of fracture. One occurred at the punch profile radii like the uniform sheet, when a softening region was narrow. While, the other occurred at the wall in the drawing of the blank with large softening region.



Figure 5: Calculated results of deep drawing with (a) a flat punch and (b) a hemispherical punch.

In the case of a flat punch, the model of the softening region of lst1.6 showed the best formability and improved by more than 0.48 in LDR than the uniform sheet (Figure 5(a)). On the other hand, in the case of a hemispherical punch the model of the softening region of lst1.2 and 1.4 showed the best formability and improved by 0.60 in LDR than the uniform sheet (Figure 5(b)). These predictions are almost the same as the results of the experiment.

5. Discussion

The experimental and calculated results show the optimal softened region for a hemispherical punch is larger than that for a flat punch. In the initial stage of forming with a hemispherical punch, a dome shape is formed by stretching, and then a cylindrical body is drawn. Sheets are broken at the top of a hemispherical punch in the stretch process when sheets are not softened or softened regions are small. Figure.6 shows the thickness strain distribution of formed sheets in the initial stage (punch stroke=12mm) of hemispherical punch forming. When the softened region is large like LST1.2, deformation (thickness reduction) of the part near the heated dies boundary is more promoted than LST1.6, therefore the thickness reduction of the sheet at a punch top is restrained. Thus the optimal softened region in the hemispherical punch drawing became larger than in the flat punch drawing.



Figure 6: Thickness strain distribution of the drawn cups with a hemispherical punch.



Figure 7: Calculated LDR with various heated dies and various n-values with a hemispherical punch.

If the optimal softened region is changed with stretch deformation, it is thought that this change is dependent on the strain hardening property of the sheet at a punch top, i.e., a high strength part. Figure 7 shows the calculated result of the LDR with various n-value in a high-strength part. In the calculation F-value is adjusted to keep the same tensile strength as the A6061 T6 sheets. As the n-value becomes larger and the stretch formability becomes better, the optimal softened region changes from LST1.4 to the LST1.6. And, when n-value is 0.3, the optimal softened region for a hemispherical punch becomes the same as that for a flat punch.

6. Conclusions

The local solution treatment process and the deep drawing with a flat punch and a hemispherical punch were investigated for the 6061-T6 sheets. The result can be summarized as follows:

- 1) The drawability (LDR) of the 6061 aluminum sheets is improved for both punches by local solution treatment.
- 2) The optimal softened region for a hemispherical punch is larger than that for a flat punch.
- 3) The optimal heat treatment region can be predicted with the numerical analysis.

References

- [1] Y.Tozawa , JSTP.J., 1, 1, 23, 1960.
- [2] T.Fujioka et. al. , JSTP.J., 27, 311, 1363, 1986.
- [3] P.S.BATE, H.SCHOFIELD, D.J.BARRETT: Metall. Mater. Trans. A, 29A, 1405, 1998.
- [4] T.Mori et. al., The Japanese Joint Conference for Technology of Plasticity, 38, 385, 1987.
- [5] A.Hofman, J. Mater. Process. Technol., 119, 127, 2001.