Deep Drawing With Internal Air-Pressing to Increase The Limit Drawing Ratio of Aluminum Sheet

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The effects of internal air-pressing on deep drawability are investigated in this study to increase the deep drawability of aluminum sheet. The conventional deep drawing process is limited to a certain limit drawing ratio(LDR) beyond which failure will occur. The intention of this work is to examine the possibilities of relaxing the above limitation through the deep drawing with internal air-pressing, aiming towards a process with an increased drawing ratio. The idea which may lead to this goal is the use of special punch that can exert high pressure on the internal surface of deforming sheet during the deep drawing process. Over the ranges of conditions investigated for Al-1050, the local strain concentration at punch nose radius area was decreased by internal air-pressing of punch, and the deep drawing with internal air-pressing was proved to be very effective process for obtaining higher LDR.

Key Words: Deep Drawing, Internal Air-Pressing, Limit Drawing Ratio(LDR), Al-1050

1. Introduction

Aluminum alloy sheets are inferior in press formability compared to the mild steel sheets. Most of the aluminum alloys have an r-value (plastic anisotropy value) between 0.7 and 1.0. Nonetheless, even though the r-values for the aluminum alloys are only about half of steel (Roger, 1991), they show, under the right circumstances, quite satisfactory drawing behavior. Among the aluminum alloys some noticeable differences in forming behavior on the stamping shop floor have been observed(Roger, 1991; Lange, 1985) because the relationship between the material, die design and test parameters, etc., versus the deep drawability may change with alloy systems. While many of the general metallurgical and die design principles that promote enhanced deep drawing are understood, the researches to improve the formability of aluminum sheet are still insufficient.

Deep drawing is a process for shaping flat sheets into cup-shaped articles without fracture or excessive localized thinning. The design and control of a deep drawing process depends not only on the workpiece material, but also on the condition at the tool-workpiece interface, the mechanics of plastic deformation and the equipment used.

The equipment and tooling parameters that affect the success or failure of a deep drawing operation are the punch and die radii, the punch and die clearance, the press speed, the lubrication and the type of restraint to metal flow(Hrivnak and Sobotoba, 1992; Date and Padmanabhan, 1992; Yossifon and Tisosh, 1991; Thiruvarudehelvan and Loh, 1993; Kawai et al., 1992; Johnson and Mellor, 1983). To establish the geometry of a part that can be successfully and economically fabricated from a given material, it is essential to know the limit to which the part material can be formed without reaching failure.

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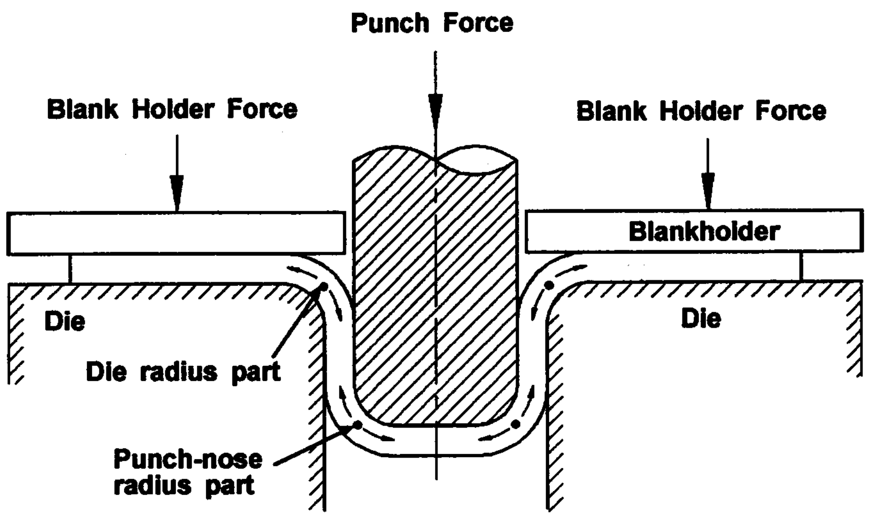


Fig. 1 Schematic drawing of deep drawing process

This forming limit depends, in addition to the shape change and process conditions, on the ability of a material to deform without failure.

The 'limiting drawing ratio'(LDR), is commonly used to provide a measure of the drawability of sheet metal, being the ratio of maximum blank diameter to punch diameter under the drawing limit without failure(Thomas and Dadras, 1981; Leu, 1997; Chen and Sowerby, 1996). It is well recognized that a high plastic anisotropy value(r-value) clearly indicated a better drawability, by inducing a high resistance of a sheet to thinning. But there is no single material parameter which satisfactorily describes the drawing behavior.

In this work, the effect of internal pressing on the formability of aluminum sheet is investigated to increase the LDR of aluminum alloys.

Figure 1 is a schematic of a cup die, showing the punch, die and blankholder, and a partially formed cup. The punch is on the down stroke and is just beginning to draw the sheet-metal blank into the die cavity. If the blank size has been chosen correctly, the metal will work harden sufficiently to overcome the combined strength of the remainder of the blank metal and friction between it and the blankholder and the part will be successfully made. However, if the blank is too large, the part will break when the tensile strength is exceeded. The first deformation of the blank occurs between the die radius and the punch-nose radius part, since this is the part that is not supported by friction with the tooling components. The metal in this section is increasing in area as it thins out and losing much of its strength. Therefore, the strain concentrations at die radius and punch-nose radius part have been the main cause of early failure. If the strain concentration in this critical area can be released, the load carrying capacity will be increased and breakage can be avoided.

One possible way to do this is air-pressing the internal surface of the blank by using specially designed punch. Because the air-pressing can reduce the local strain concentration and thus retard an early failure.

The test methods and results are described in this article.

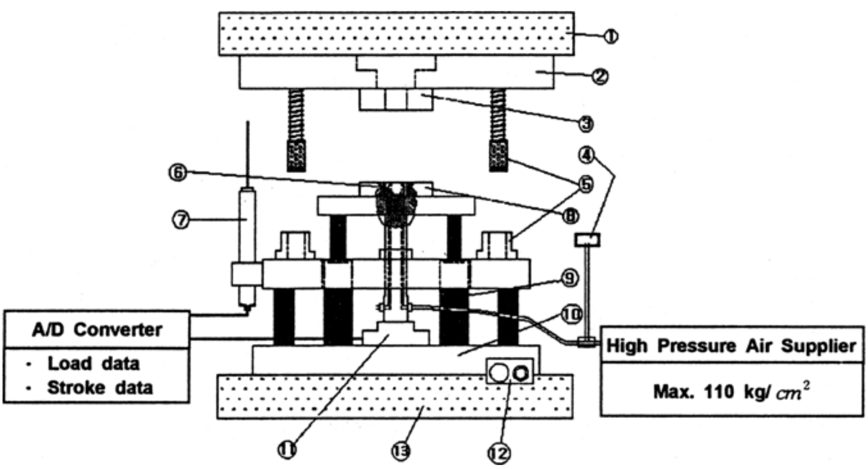
2. Experimental Procedure

2.1 Material and equipment

Commercially available Al-1050 aluminum sheet with a thickness of 1.0 mm is used for the blank material. Tensile property of the Al-1050 is shown in Table 1.

Table 1 Tensile property of Al-1050

Test direction	Tensile properties			Formability parameters		
	Yield stress (kg/mm^2)	Tensile stress (kg/mm^2)	Uniform elongation	$r = \varepsilon_w/\varepsilon_t$	$r_m = (r_0+2r_{45}+r_{90})/4$	$r_m = (r_0-2r_{45}+r_{90})/2$
0°	11.72	12.84	0.020	0.67	0.58	0.25
45°	12.57	13.56	0.019	0.45		
90°	12.95	13.84	0.017	0.73		



1. Ram
2. Upper plate
3. Die
4. Direction control valve
5. Centering guider
6. Punch
7. LVDT
8. Blank holder
9. Nitrogen gas spring
10. Lower plate
11. Load cell
12. Gas pressure gauge
13. Bolster

Fig. 2 Experimental setup of deep drawing process

Preliminary experiments show that blanks with diameters of less than 70mm are drawn without failure. Therefore blank diameters are progressively increased by 1 mm from the blank diameters of 70 mm. When failure of blank occurs, experiments proceed with the diameter increasing or decreasing 1 mm to ascertain the maximum diameter of the blank sheet without failure in cup-drawing for estimating the LDR-value.

Figure 2 shows the deep drawing machine that is used in this investigation. It is a hydraulic press with a maximum load capacity of 50 Ton and a variable punch speed of 1 mm/sec~15 mm/sec. In this press, the punch is mounted on the lower shoe and the die on the upper shoe of the machine. The punching and blank-holding forces and the punch stroke can be measured separately by indicators those are provided on the machine.

Proper tool steel with appropriate mechanical properties and hardening treatment is used for the materials of the punches and dies. The tools are ground to an appropriate surface finish and a final hardness of 60HRC.

Figure 3 schematically shows punch and die set used in this study. For the air-pressing, the punch has been bored out and high pressure air line was connected. This arrangement was used to produce internal air-pressure of maximum 110 kgf/cm2. The geometry of the punch and die, especially

Table 2 Experimental conditions

Air pressure(kg/cm^2)	Ram speed(mm/sec)	clearance(%)
0, 10, 20, 30, 40, 50, 60, 70	4	20

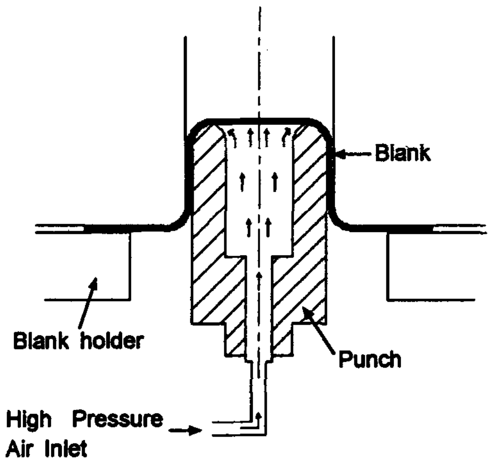


Fig. 3 Schematic drawing of punch and die set

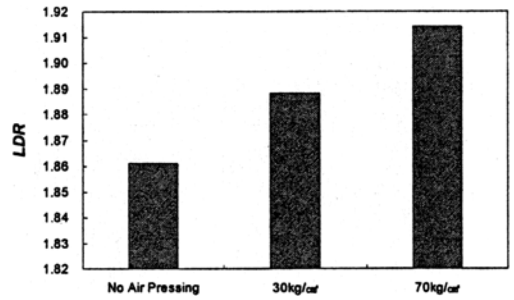


Fig. 4 Obtained LDR with increasing air pressure

their profile radii, are the major variables in deep drawing processes. It has been shown[8] that for a punch nose radius, rp, that is less than twice the thickness of the blank, to, the cups fail due to tearing, while for punch nose radius that is larger than 10 to stretching may be introduced. In addition, within the region $4 \cdot t_0 < r_p < 10 \cdot t_0$ the radius does not significantly affect the limiting drawing ratio(LDR). Therefore, according to the thickness of the blank, the most suitable shoulder radii for the dies and punches were selected to be 6mm with a constant punch diameter of 38.6mm.

2.2 Test procedure

A proper drawing speed is important for the deep drawing process: excessive speeds can cause wrinkling or fracture in the formed part and damage of the tooling: while insufficient speeds reduce the rate of production. In this investigation a drawing speed of 4 mm/sec is found to be the most suitable speed. The blank holder force is chosen to be the minimum force required to prevent wrinkling of the largest blank and is found to be 350kgf. An operation sequence is arranged for the tests and the punch forces are measured simultaneously as function of test variables. The air-pressure is applied until the load reaches the maximum load because the air-pressing after reaching the maximum load no longer affect better deep drawability. Each test is repeated two or three times, average values being obtained. All experiments were carried out by the cup-drawing operation shown in Fig. 3 and experimental variables applied in this study are described in Table 2.

Press oil, commercial grade high pressure hydraulic oil, is brushed on to the blank before forming to diminish the friction at the contact interface.

The effectiveness of the air-pressing was judged by LDR that is determined by the maximum size of blank that could be formed into a cup, since the blank size determines the maximum cup depth, and can be measured more accurately.

3. Results and Discussion

To investigate the effect of air pressing on the deep drawability, the LDR is obtained at each process condition. For the calculation of LDR, the maximum blank diameter, this diameter being that below which the blanks will be drawn successfully and above which tearing will occur in the cup wall is determined.

Figure 4 shows the variation of LDR with increasing air pressure for Al-1050 and Fig. 5 shows photograph of deep drawn cups at given

Fig. 5 Comparison of deep drawn depth
(a) LDR=1.862(No air pressing)
(b) LDR=1.915(Air pressure=70kg/cm²)

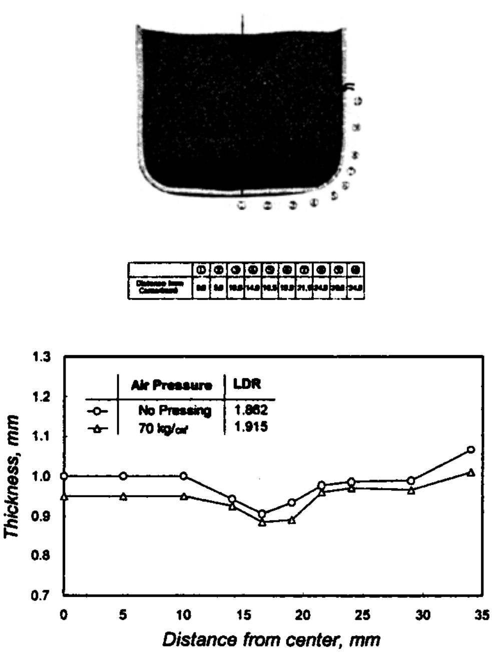


Fig. 6 Thickness profile of cross sectioned cup

process conditions.

Above figures show that higher LDR is obtained at higher internal air-pressure. The reason for the increased LDR at higher air pressure can be explained by thickness profile of cross sectioned cup shown in Fig. 6.

Figure 6 shows that the overall thickness of deep drawn cup and the degree of thickness variation at rounding part are decreased at the air pressure of 70 kg/mm^2. The relatively steep decrease in thickness at rounding part that had touched with punch nose radius reflects the local strain has been concentrated on this part. Therefore, the decrease in the degree of thickness variation at the rounding part confirms that the local strain concentration has been relaxed by air-pressing.

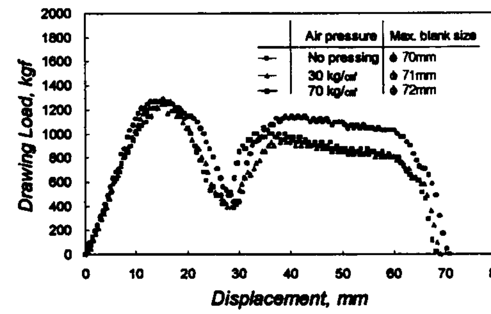


Fig. 7 Comparison of drawing load with increasing air pressure

Figure 7 shows the effect of the air pressure on the drawing load-displacement curves. In general, an increase in the drawing force is observed for larger blank diameters due to the enlargement of fictional interfaces such as the die-blank and blankholder- blank interfaces. While the figure indicates that the maximum drawing loads are not so significantly increased even with increasing maximum blank diameters at higher air pressure. It means that the internal air-pressing contribute to the reduction of drawing load possibly by reducing friction between punch and blank. In other words, the internal air-pressing itself does not alter the deformation resistance of deforming sheet blanks, but has an effect on the manner of the transmission of the load at punch nose radius part and increases LDR of blank.

Although the experimental conditions used in this study may not be the optimum for the highest LDR, the trends obviously shows that the internal air pressing is advantageous for higher LDR. The effectiveness of the air pressing process depends on how well the metal can be pressed. Therefore, the effect of air-pressing process will be more prominent for aluminum alloy sheets than mild steel sheets.

4. Conclusion

The air-pressing method is proved to be very effective in increasing the deep drawability of Al-1050. On the basis of the experimental investigation made herein, higher air pressing guarantees higher LDR. The increased LDR is mainly caused by the relaxation effect of local strain concentration at punch nose radius area. The results that have been described above show that air-pressing method also has the potential to increase the LDR of other metal alloy sheets.

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