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Development of Press Forming Technologies of Aluminum Alloy Sheets by Servo Press

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This paper presents the effect of the functions of a servo press on the sheet metal forming of an aluminum wrought alloy. Rectangular cup deep drawing tests and hat-shaped bending tests were performed using AA6022-T4 aluminum alloy automotive body sheets. In the rectangular cup deep drawing tests, the fracture limit is improved by increasing the speed of forming. Both the necking at the punch shoulder and the wrinkle at the flange are maintained within acceptable limits by controlling the blank holder force (BHF) of the die cushion. In the hat-shaped bending tests, springback is influenced by BHF, forming speed, and lubricant viscosity. The springback is closely related to the punch load at the end of the forming process. Formability and shape fixability are improved by controlling both the slide motion and the BHF of the die cushion of a servo press.

Keywords: *aluminum alloy, sheet metal forming, formability, shape fixability, servo press*

1. Introduction

The use of aluminum alloy sheets is effective in reducing the weight of automotive bodies. In fact, commercial aluminum alloy sheets are being used to manufacture to some stamped parts such as engine hoods, roofs, fenders, trunk lids, and doors of automobiles. However, the use of aluminum alloy sheets is mostly limited to shallow-drawn parts such as the inner panel and the outer panel of an engine hood. Because the formability and shape fixability of the aluminum alloy sheets are generally inferior to those of low-carbon steel sheets, it is difficult to use aluminum alloy sheets to form complex deep-drawn parts such as a fender panel, the inner panel of a door, and the inner panel of a trunk lid; considerable time is consumed in trial stamping and reshaping the die.

An improvement in the formability and shape fixability of sheet metal forming is required for the use of aluminum alloy sheets to manufacture complex deep-drawn parts. A further reduction in the weight of automotive bodies will be achieved by using aluminum alloy sheets to manufacture complex deep-drawn parts.

Recently, the use of servo presses has increased because of their high productivity and low noise. Servo presses offer high flexibility in controlling the speed of slide motion and the blank holder force (BHF) of a die cushion. However, the sheet metal forming for aluminum wrought alloys, with the purpose of improving the formability and shape fixability, has not yet been proposed. In this study, rectangular cup deep drawing tests and hat-shaped bending tests were performed to investigate the effect of the functions of the servo press on the sheet metal forming of an aluminum wrought alloy.

2. Servo Press, Blank Sheets, and Lubricants

A hybrid AC servo press H2F300 (Komatsu Industries Corp., Tokyo, Japan) was used for both types of tests. The slide of the servo press has a maximum load of 3000 kN; slide speed is controlled by two servomotors. The die cushion has a maximum BHF of 400 kN; BHF of the die cushion is controlled by another set of two servomotors. The blank sheets used are AA6022-T4 automotive body sheets of thickness of 1 mm. Table 1 lists the mechanical properties of AA6022-T4. The lubricants used are R-303P, which is a low-viscosity anti-rust oil, or RS-962, which has a higher viscosity than R-303P. The viscosity of the lubricants is given in Table 2.

Table 1. Mechanical properties of AA6022-T4

Tensile Direction θ / °	Tensile Strength σ_{TS} / MPa	Proof Stress σ_{PS} / MPa	Elongation δ / %
0	256	139	33.1
45	254	138	33.8
90	250	135	32.7
Average	254	137	33.4

Table 2. Viscosity of lubricants

Lubricant	Viscosity ν / mm^2/s
R-303P	3.9
RS-962	16.5

3. Rectangular Cup Deep Drawing Tests

3.1 Experimental procedure

The experimental conditions are listed in Table 3. Figure 1 shows slide speed diagrams. Link motion is a motion that simulates the movement of a crank press. In Link motion, the rotational frequency of servomotors is constant; the speed of the slide motion is decreased from the beginning. In Controlled motion, the servomotors of the slide are controlled as the speed of the slide motion is increased from the beginning. The BHF diagrams of the die cushion are given in Figure 2. In the Constant BHF pattern, the BHFs are 150 and 200 kN in the forming process, while in the Controlled BHF pattern, the BHF is decreased from the initial 300 kN to the final 100 kN. The blank sheets are octagons as the corner edges of 420 mm × 280 mm rectangles are cut off.

In order to evaluate the failures (i.e., fracture or necking) in the punch shoulder, a deformation at the punch shoulder is checked by measuring a scribed circle having a diameter of 10 mm. In order to evaluate a wrinkle in the flange, the roughness of the flange is measured by using a profilometer; the wrinkle in the flange is checked by observing the distribution of curvature.

Table 3. Experimental conditions for rectangular cup deep drawing tests

Tool	Punch	Die
Width × Length / mm	150 × 300	152.8 × 302.8
Radius corner / mm	30	31.4
Radius shoulder / mm	5	8
Forming height / mm	44	
Lubricant	RS-962	
Slide motion	Link motion, Controlled motion	
Die cushion	Constant BHF, Controlled BHF	

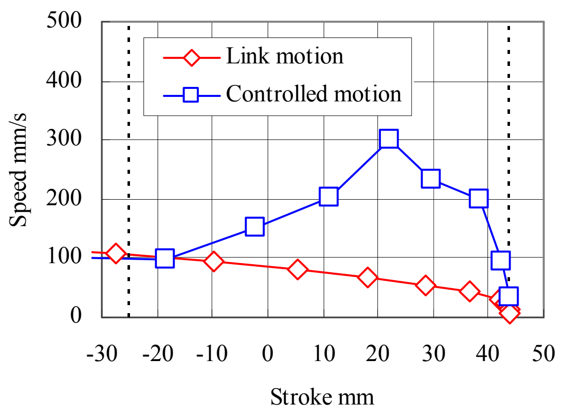


Fig. 1. Speed diagrams of slide motion

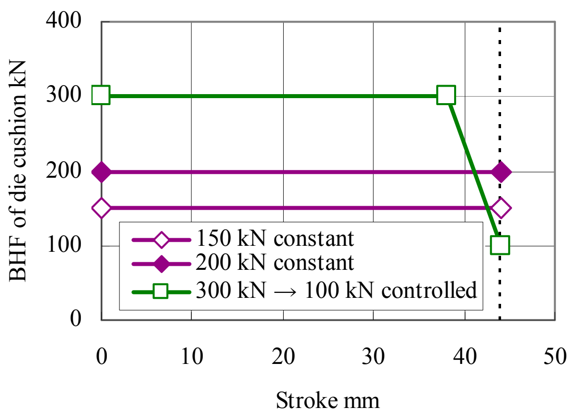


Fig. 2. BHF diagrams of die cushion

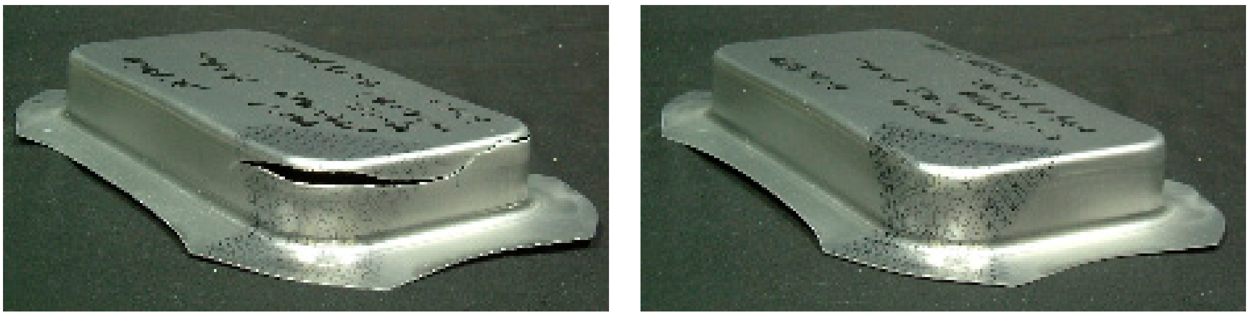
3.2 Results and discussions

3.2.1 Improvement in fracture limit by controlling slide motion

In the case of the constant BHF (150 kN in the forming process) of the die cushion, the tests were carried out by using two types of slide motions—Link motion or Controlled motion. The states at the punch shoulder are shown in Figure 3. A fracture occurred in the case of Link motion. On the other hand, the deformation was safe in the case of Controlled motion. It is known that the friction coefficient depends on the sliding speed and the surface pressure [1–2]. When the sliding speed is increased under a mixed elastohydrodynamic lubrication condition, the friction coefficient tends to decrease. The Controlled motion was fast as compared to the Link motion; therefore, the sliding speed at the flange was high and the value of the friction coefficient decreased. It could be assumed that the drawing resistance was decreased by the reduction in the frictional force. However, the wrinkle at the flange was observed in the case of both the Link motion and the Controlled motion.

3.2.2 Improvement in necking and wrinkle limit by controlling the blank holder force of the die cushion

In the case of Controlled motion, the tests were carried out by using a constant BHF (200 kN in the forming process) of the die cushion or a controlled BHF (a decreasing force from the initial 300 kN to the final 100 kN). The maximum major strain ε_1 at the punch shoulder is shown in Figure 4. Controlled BHF ensured that the growth of the maximum major strain remained less than the strain in the case of the constant BHF. The curvature distribution of the measured line at the flange is shown in Figure 5. The curvature changed periodically in the case of constant BHF. On the other hand, the periodic change in the curvature was within the acceptable range in the case of the controlled BHF.



(a) Link motion (b) Controlled motion

Fig. 3. States at the punch shoulder in the case of constant BHF (150 kN).

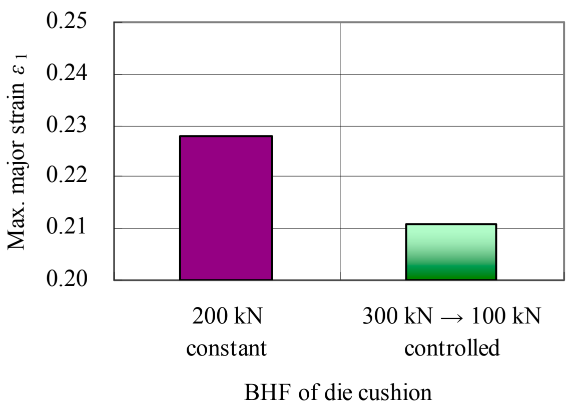


Fig. 4. Maximum major strain ε_1 at the punch shoulder in the case of Controlled motion

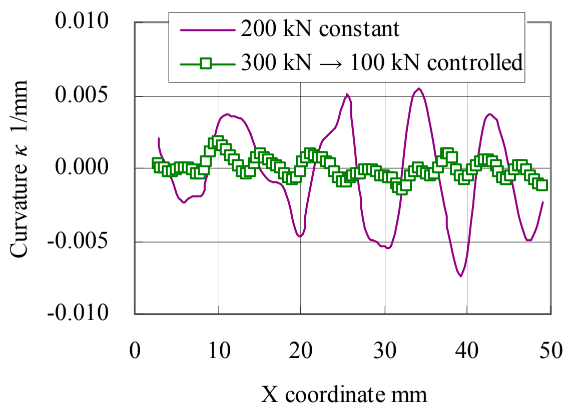


Fig. 5. Curvature distribution of measured line at the flange in the case of Controlled motion

4. Hat-shaped Bending Tests

4.1 Experimental procedure

The experimental conditions for these tests are listed in Table 4. The Speed diagrams of the slide motion are shown in Figure 6. Link motion is a motion that simulates the movement of a crank press. In Controlled motion, the speed of the slide motion is less than 5 mm/s at 74 mm. The BHF diagrams of the die cushion are given in Figure 7. In constant BHF patterns, the BHFs are 50, 100, and 150 kN in the forming process, whereas in the controlled BHF pattern, the BHF is increased from the initial 50 kN to 350 kN at 75 mm. The blank sheets are 350 mm × 100 mm rectangles.

In order to evaluate the springback, the width (W) at a position 65 mm away from the punch base of the formed sheets was measured. The percentage of the deviation from the design width (W0 = 150 mm) was defined as the width expanded ratio ((W – W0)/W0 × 100), which was an indicator of shape fixability.

Table 4. Experimental conditons for hat-shaped bending tests

Tool	Punch	Die
Width / mm	150	152.8
Radius shoulder / mm	5	8
Forming height / mm	80	
Lubricant	R-303P, RS-962	
Slide motion	Link motion, Controlled motion	
Die cushion	Constant BHF, Controlled BHF	

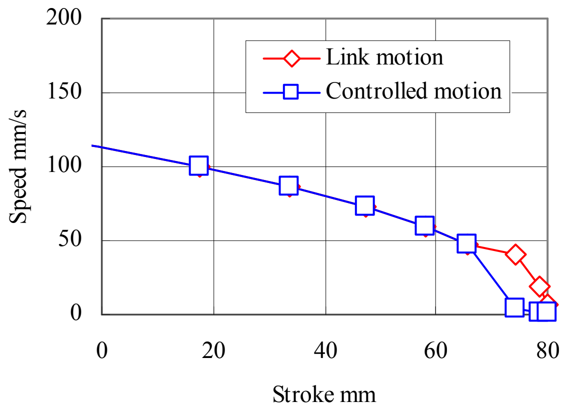


Fig. 6. Speed diagrams of slide motion

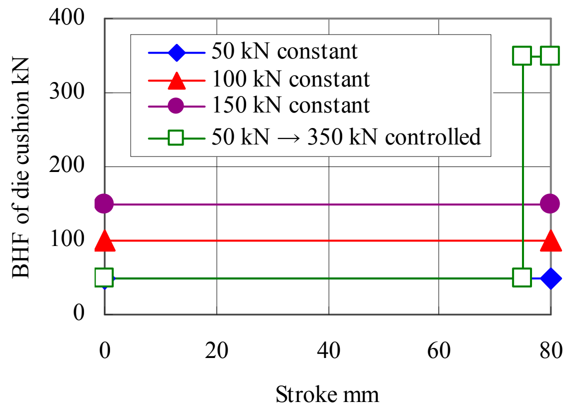


Fig. 7. BHF diagrams of die cushion

4.2 Results and discussions

The appearance of formed sheets and the width expanded ratio ((W – W0)/W0 × 100) are shown in Figure 8.

4.2.1 Improvement in shape fixability by controlling the blank holder force of the die cushion

In the case of the lubricant R-303P and Link motion, the tests were carried out by maintaining a constant BHF (50, 100, or 150 kN in the forming process) of the die cushion. As the BHF was increased, the width expanded ratio decreased; however, the blank sheet slipped during the forming process in the case when the constant BHF was equal to150 kN. It was estimated that there was a slight difference in the BHF between the flanges on both sides. We assumed that the tension difference on both sides was caused before the punch shoulder was completely formed when a large BHF was applied from the beginning; therefore the blank sheet slipped.

In the case of the same lubricant and slide motion as those in the above paragraph, the tests were also carried out by using a controlled BHF (which was increased from the initial 50 kN to 350 kN at

75 mm) of the die cushion. The width expanded ratio could be kept within 5% or less, the blank sheet did not slip during the forming process.

In the case of lubricant RS-962 and the Link motion, the tests were carried out by using the same controlled BHF as that mentioned in the previous paragraph. In this case, the width expanded ratio could not be kept within 5%. Because the viscosity of RS-962 was higher than that of R-303P, it was estimated that the frictional coefficient of RS-962 was lower than that of R-303P. If the BHF was increased to 350 kN at 75 mm, the frictional force at the flange could not be increased, and a considerable amount of tension did not occur at the sidewall. Therefore, the non-uniformity of the stress in the thickness direction could be decreased.

4.2.2 Improvement in shape fixability by controlling both the slide motion and the blank holder force of the die cushion

In the case of the lubricant RS-962 and the same controlled BHF as that mentioned in the previous paragraph, the tests were carried out by using Controlled motion (the speed of the slide motion was less than 5 mm/s at 74 mm). The width expanded ratio could be kept within 5 % or less, and the blank sheet did not slip during the forming process. The BHF increased at the end, and the frictional coefficient increased because of the significant reduction in the sliding speed at the end of the forming process. Therefore it could be assumed that the frictional force at the flange increased considerably.

4.2.3 Relationship between punch load at the end and the width expanded ratio

The relationship between $P_{Fin.}/(A0 \times TS)$ and the width expanded ratio is shown in Figure 9. Here, $P_{Fin.}$ is the punch load at the end of the forming process, A0 is the sectional area of the blank sheet, and TS is the tensile strength of the blank sheet. There is a linear relationship between $P_{Fin.}/(A0 \times TS)$ and the width expanded ratio. If $P_{Fin.}/(A0 \times TS)$ is increases, the width expanded ratio shows the tendency to decrease; this tendency is independent of the lubricant.

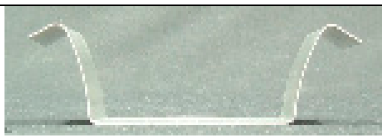
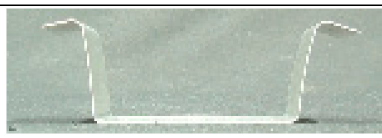
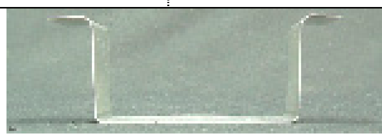
					
$(W - W0)/W0 \times 100 = 37.5\%$		$(W - W0)/W0 \times 100 = 23.0\%$		$(W - W0)/W0 \times 100 = 11.8\%$	
Slide motion	Link motion	Slide motion	Link motion	Slide motion	Link motion
BHF of die cushion	50 kN constant	BHF of die cushion	100 kN constant	BHF of die cushion	150 kN constant
Lubricant	R-303P	Lubricant	R-303P	Lubricant	R-303P
					
$(W - W0)/W0 \times 100 = 2.8\%$		$(W - W0)/W0 \times 100 = 21.7\%$		$(W - W0)/W0 \times 100 = 2.0\%$	
Slide motion	Link motion	Slide motion	Link motion	Slide motion	Controlled motion
BHF of die cushion	50 kN → 350 kN controlled	BHF of die cushion	50 kN → 350 kN controlled	BHF of die cushion	50 kN → 350 kN controlled
Lubricant	R-303P	Lubricant	RS-962	Lubricant	RS-962

Fig. 8. Appearance of formed panels and width expanded ratio ($(W - W0)/W0 \times 100$)

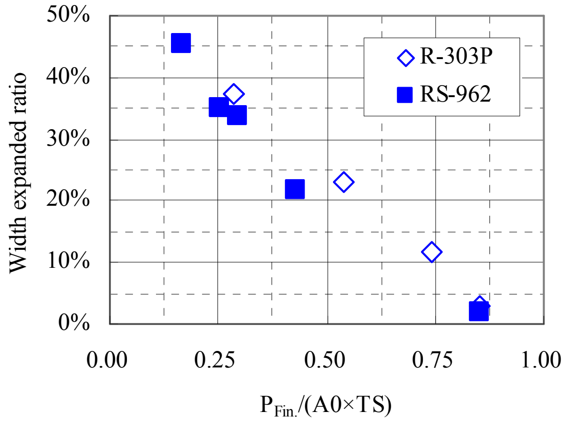


Fig. 9. Relationship between punch load at the end and the width expanded ratio

5. Conclusions

In this study, the effect of the functions of the servo press on the sheet metal forming of an aluminum wrought alloy was investigated. The results obtained in this study are as follows:
1) In rectangular cup deep drawing tests, the fracture limit was improved by increasing the speed of forming. Deformation at the punch shoulder and wrinkle at the flange were maintained within acceptable limits by controlling BHF of the die cushion.
2) In hat-shaped bending tests, springback was influenced by BHF, speed of forming, and viscosity of the lubricant. The springback was closely related to the punch load at the ending.

Formability and shape fixability were improved by controlling both the slide motion and the BHF of the die cushion of the servo press.

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