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Springback of FCC sheet in warm forming

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These days, automobile industry tends to use aluminum alloy sheets to reduce weight of auto-body. However, aluminum alloy sheets have the drawback that they have tremendous springback in press forming operations. Springback deteriorates accuracy of the product as well as causes difficulties in assembling the parts such that technical plans for springback reduction before pressing have to be prepared. In this paper, the warm forming method, which changes material properties, is proposed to decrease springback. In order to suggest the warm forming method, first, the material properties of aluminum alloy sheets, AL1050 and AL5052, in high temperatures such as yield stress, plastic strain ratio, Young's modulus, true stress-strain curve, etc. are obtained from tensile tests. Next, the bending and draw bending tests in various forming temperatures are performed to measure the springback in various forming temperatures. Two kinds of experiment show that the springback tremendously reduces in warm forming, specially in the forming temperatures of above 150°C.

Key words: Springback, Worm forming aluminum alloy sheets, Tensile test in high temperature, Stretch bending, Draw bending.

Introduction

Recently, the researches in automobile industries trend toward weight reduction for improving fuel consumption as environmental problems in exhaust gas socially arise such that aluminum alloy sheets are intensively interested in instead of general steel materials. However, the aluminum alloy sheet has the drawbacks that it more easily tears during the flow into die cavity than the steel sheet because it has a larger thickness strain than the steel sheet. And aluminum alloy has relatively big springbacks due to small elastic modulus (about 1/3 of ferrous sheet). Furthermore, the springback can be the origin of the defect of dimensional accuracy in a product.

Springback occurs in various forms like torsion, bending, twisting, etc. and is known to have many factors affecting it, such as blank holding force, punch velocity, lubrication condition, die shape, blank size, etc. Besides these forming variables, the material properties like Young's modulus, yield strength, Bauschinger effect, etc. are also intensively related to the springback. However, neither the database for fixing the springback is established in automotive industries, nor the theory for explaining the springback is set up well in academic institutes although the solution for the springback problem is pursued by the research on material heat treatment or a novel forming technology. These days, many stamping engineers in the field rely on the trial and error as well as the experience of die designer.

As the aluminum alloys have the property of a high ductility along with a low tensile strength in the forming temperature range of 200°C-300°C, they can improve the formability and reduce springback by heating the material directly or by heating the dies during the forming so that the heat is transferred to the material. So far, this method has been mainly applied to ferrous sheet formings.

Although the researches related to the aluminum alloys is insufficiently performed except for some experimental consideration, they are recently interested in as novel research issues for a light car body. One of the novel researches is a study on the warm forming method. Because the warm forming method enables the drawing and stamping complex geometry parts without tears, the hardening soft materials without heat treatment processes, and the reducing springback phenomena by changing material properties in high temperatures, the big advantages in productivity, quality improvement, and cost, etc. are expected.

Kuwabara *et al.* [1] introduced a springback calculation for a normal anisotropy material following the n-th power hardening law and simulated the springback using his theory. They considered a sheet behavior in four load conditions under the assumption of plane deformation and plane stress conditions and compared their analysis results with experimental ones for Ak sheet and Al5182-O aluminum alloy sheet.

Zhang and Lee [2] presented their mathematical model and compared it with other investigator's model and studied the effect of process variables and material properties on the springback. Wagoner *et al.* [3] did the research about the effect of exact stress analysis on the evaluation of springback. They compared simulation

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results using commercial program, Z-Band and LS-Nike/Dyna, with experimental results. Leu *et al.* [4] considered plastic strain ratio (bar R) and strain hardening exponent(n) in calculating the springback and compared simulation result with experiment result. Yang *et al.* [5] estimated the sensitivity of the modeling parameters, such as penalty constant, element size, number of elements in curved area, and punch velocity when the springback phenomenon is calculated by finite element method and analyzed the springbacks of loof panel and S-rail of NUMISHEET'96 benchmark problem. Oh *et al.* [6] predicted the process variables that minimize the springback in a deep-drawing process of aluminum square container. Chung *et al.* [7] carried out forming analysis with an explicit FEM program and springback analysis with an implicit FEM program. They solved S-Rail benchmark problem and evaluated the efficiency of their program. Park *et al.* [8] applied temperature difference to upper and lower faces of the sheet for reducing the springback occurring during the bending process and verified their method effects.

In this study, the springback of aluminum alloy sheet in the warm forming is experimentally evaluated and the proper forming temperature is suggested. Furthermore, the quantitative evaluation of springback in warm forming process is theoretically considered.

Experiments

Tensile Test in High Temperatures

In order to find the material and mechanical properties needed in investigating the theoretical background of the springback phenomena of aluminum alloys in warm forming condition, the tensile tests in high temperatures were performed. The chemical compositions of test specimens, AL1050 and AL5052, are summarized in Table 1. The thickness of the specimens is 0.8 mm. Figure 1 shows the dimension of the specimen. The specimens are respectively prepared in 0^o, 45^o, and 90^o from the rolling direction.

The tests were carried out over the temperature range from 18^{o}C to 350^{o}C after holding a testing temperature for 30 minutes at a speed of 5mm/min. The true stress-strain curves of AL1050 and AL5052 sheets associated with various test temperatures are shown in Fig. 2, in which the stress-strain points experimentally measured are analytically interpolated with power law equation. It is seen that, as a test temperature rises, especially over 150^{o}C, the material properties such as yield stress, tensile strength, elastic modulus, strength coefficient, and strain hardening exponent rapidly decrease, whereas elongation and plastic strain ratio increase. The values of yield stress vary amply with a test temperature change. The formability seems to be remarkably enhanced as

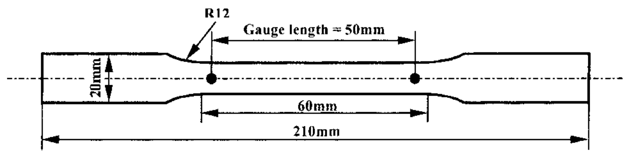

Fig. 1. Dimension of tensile specimen.

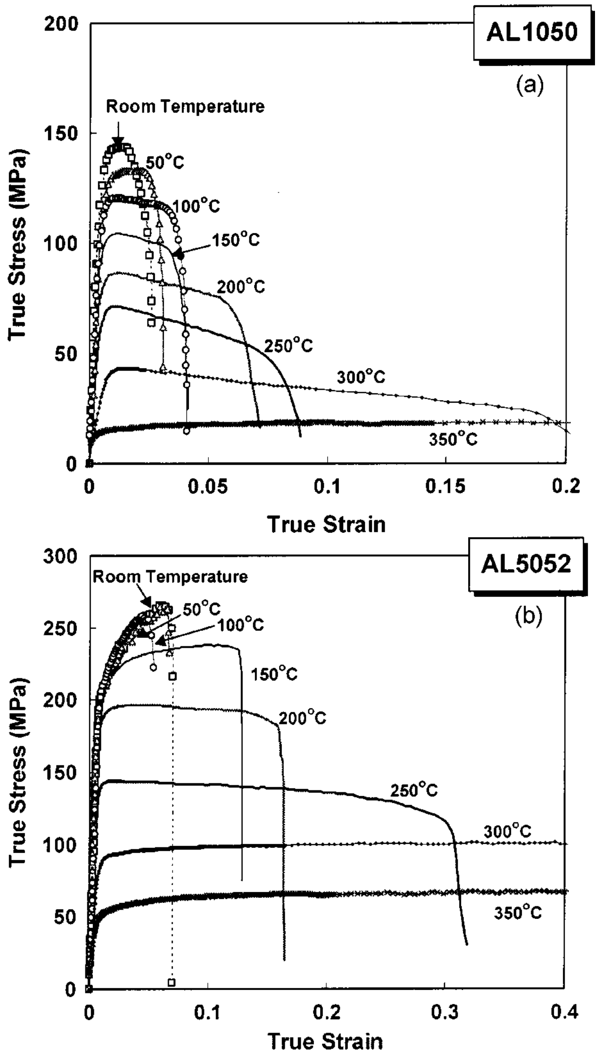

Fig. 2. True stress-strain curves of (a) AL1050 and (b) AL505 sheet specimens associated with test temperatures from room-temperature (R.T) to 350^{o}C.

Table 1. Chemical composition of AL1050 and AL5052

Alloy number	Al	Mg	Cr	Ti	Fe	Si	Cu	Mn	V	Zn
AL1050	Min 99.5	Max 0.05		Max 0.03	Max 0.4	Max 0.25	Max 0.05	Max 0.05	Max 0.05	Max 0.05
AL5052	97.3	2.2-2.8	0.15-0.35		Max 0.4	Max 0.25	Max 0.1	Max 0.1		Max 0.1

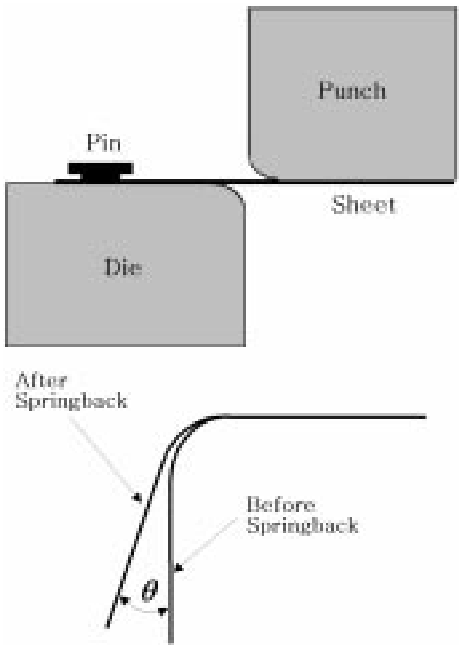

Fig. 3. Schematic view of experimental apparatus for stretch bending test and springback.

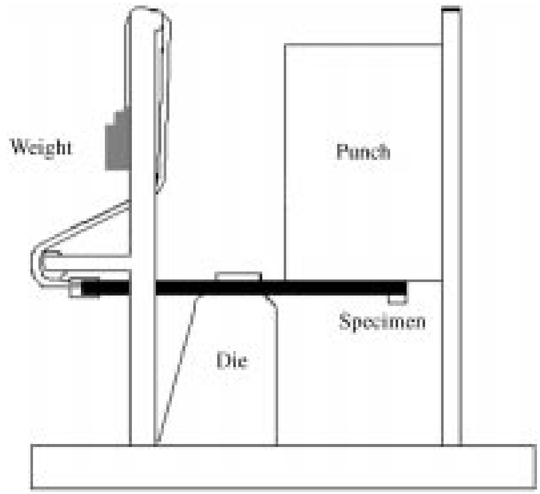

Fig. 4. Schematic view of Experimental apparatus for draw bending test.

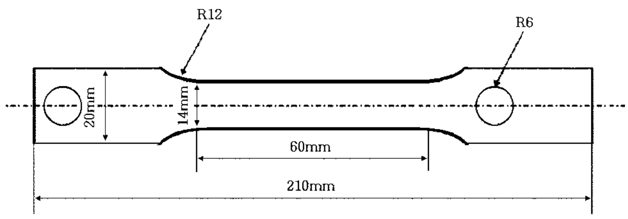

Fig. 5. Dimension of the specimen for draw bending test.

the testing temperature rises.

Springback Test

Stretch Bending Test

The stretch bending test as well as draw bending test were chosen for evaluating a springback behavior of aluminum alloys experimentally. The springback tests are performed in a furnace changing the testing temperature from room temperature to 350ºC with the interval 50ºC.

For the stretch bending test, the scaled bending dies are manufactured and the experimental apparatus as well as tooling are shown in Fig. 3. Radii of die shoulder and punch corner are 10 mm and 2 mm, respectively. Clearance between die and punch is 1.2 mm. The test specimens with a size of 150 mm $\times$ 30 mm were prepared in 3 directions, 0º, 45º, 90º, from the rolling. In the furnace where the testing temperature can be changed and kept, the stretch bending test were carried out after the scaled dies and specimen hold the testing temperature for 30 minutes. During the test, the testing temperature inside the furnace was measured using the thermocouple. Springback amount was measured after removing the punch outside the furnace.

Draw Bending Test

As the stretch bending test, the forming temperatures in the test started from room temperature to 350ºC with the interval 50ºC. For the draw bending test, the scaled dies seen in Fig. 4 are manufactured. The radii of die shoulder and punch corner are 10 mm and 2 mm, respectively. The clearance between die and punch is 1.2 mm. The weight pulling the sheet at one end in the die side controls the blank holding force. The specimen showing the dimension in Fig. 5 has the thickness 0.8 mm. The specimens are prepared in the rolling direction only because the stretch drawing test showed no big difference in the springback in all directions. The draw tests were carried out in a furnace in which the forming temperature was measured by the thermocouple. Once reaching the forming temperature in the test in a furnace, the holding time of at least 30 minutes was kept for maintaining the forming temperature of the

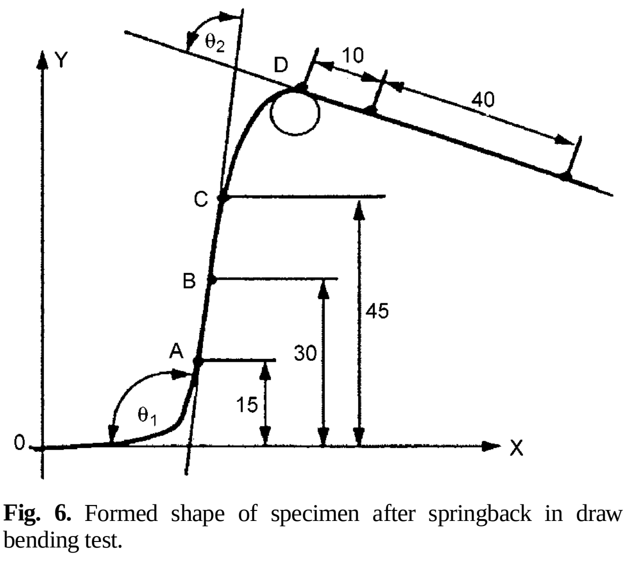

Fig. 6. Formed shape of specimen after springback in draw bending test.

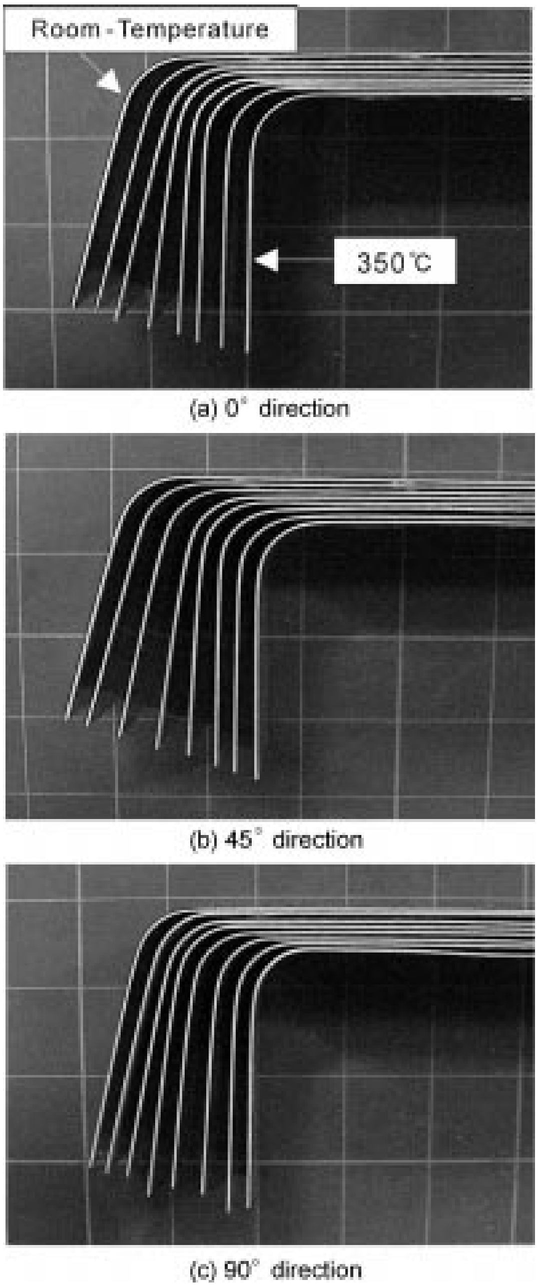

Fig. 7. Springbacks of AL1050 sheets in (a) 0° direction (b) 45° direction and (c) 90° direction from the rolling direction after stretch bending test associated with test temperatures from room-temperature (R.T) to 350°C.

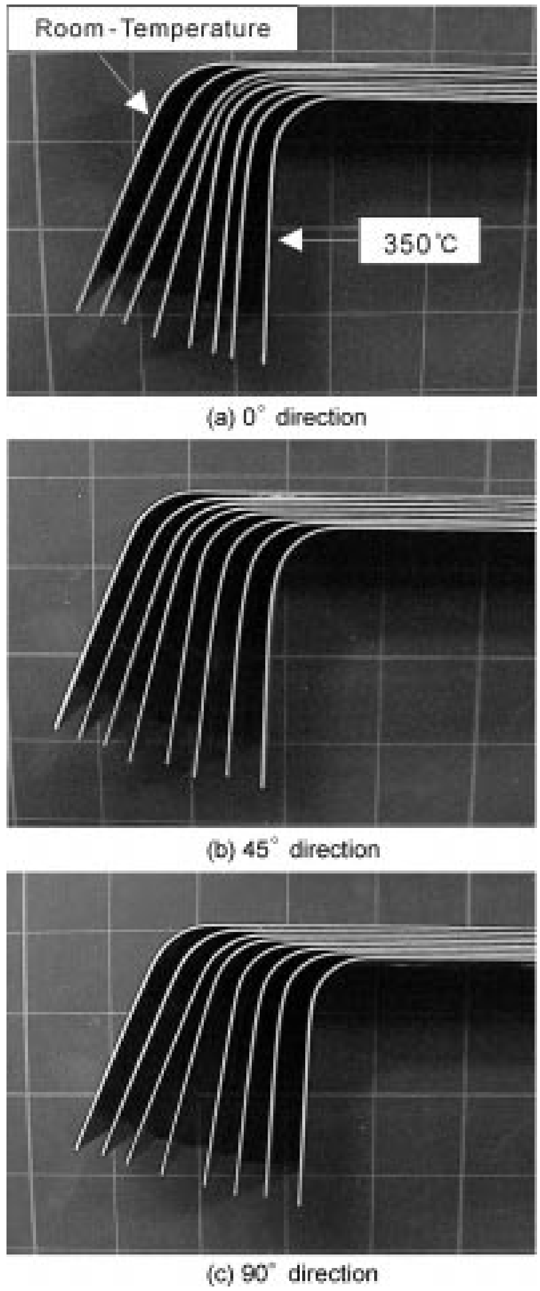

Fig. 8. Springbacks of AL5052 sheets in (a) 0° direction (b) 45° direction and (c) 90° direction from the rolling direction after stretch bending test associated with test temperatures from room-temperature (R.T) to 350°C.

specimen during the testing. After measuring the angles, $\theta 1$ and $\theta 2$, shown in the Fig. 6 before and after springback, the springback amounts, $\delta\theta 1=\theta 1-90$ and $\delta\theta 2=90-\theta 2$, were measured in each specimen.

Results and Discussion

Figure 7 and Fig. 8 show the springback shapes of AL1050 and AL5052 associated with testing temperatures in 0°, 45°, and 90° from the rolling after stretch bending tests, respectively. As the testing temperature becomes higher, the springback amount becomes smaller. This implies that the warm forming can reduce the springback.

Figure 9 shows the numerical springback amounts associated with the testing temperatures in 3 directions after stretch bending testing As the forming temperature increases, the springback reduces because the material properties changes in high temperatures. Specially, over forming temperature 150°C, the springback rapidly reduces. Since AL5052 has higher yield strength than AL1050, the springback of AL5052 is bigger than that of AL1050.

The springback in 3 directions are almost the same in high temperatures, while they differ a little in room

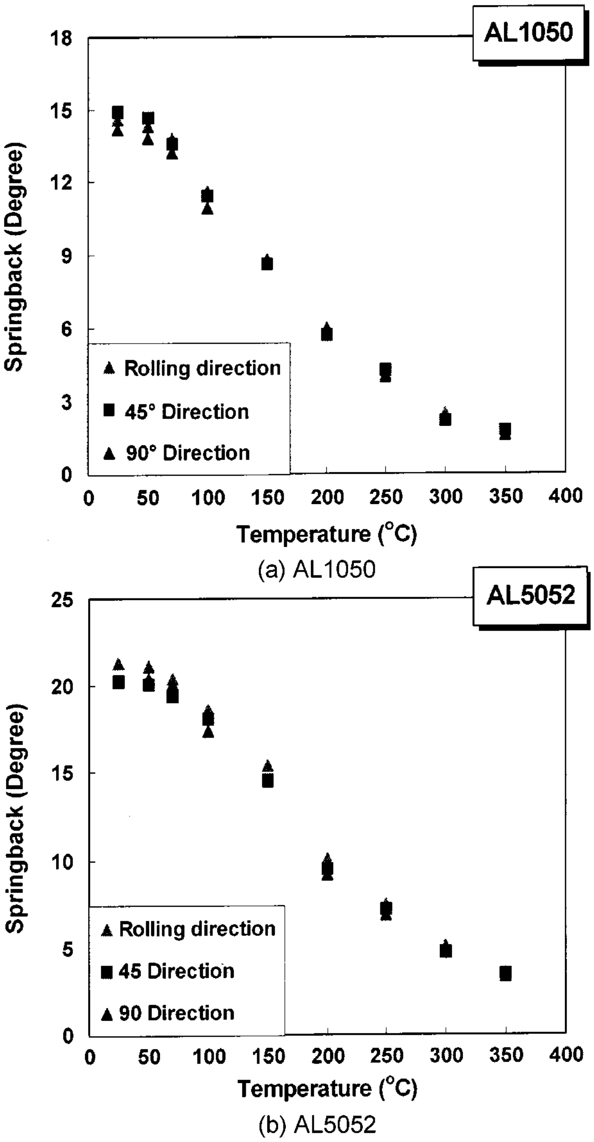

Fig. 9. Springbacks of (a) AL1050 and (b) AL5052 after stretch bending test associated with test temperatures from room-temperature (R.T) to 350°C.

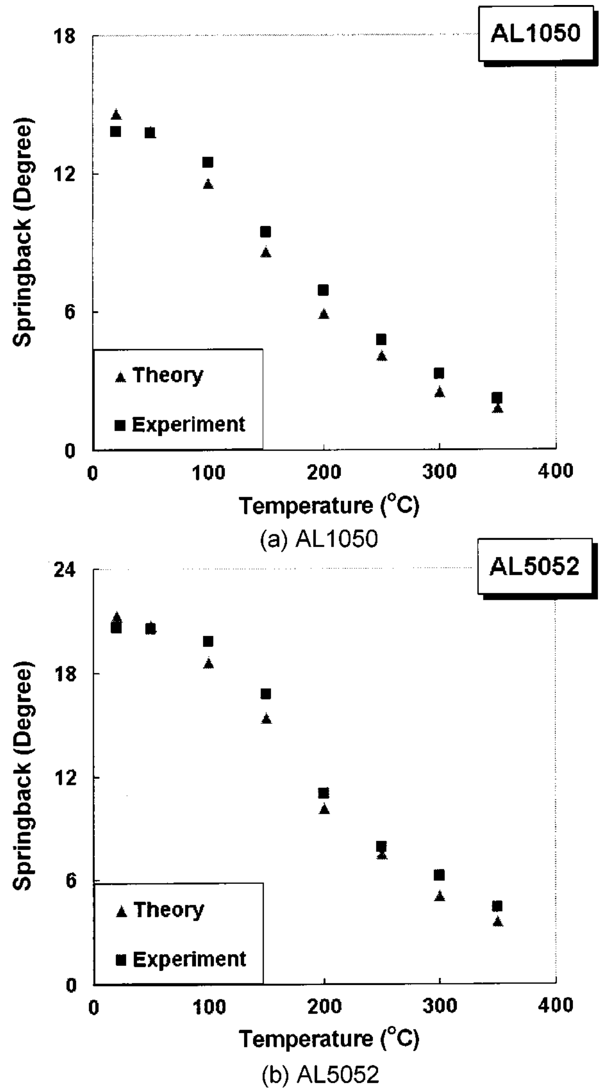

Fig. 10. Comparison of springback amounts of (a) AL1050 and (b) AL5052 after stretch bending between theory and experiment associated with test temperatures from room-temperature (R.T) to 350°C.

temperature. This is simply explained by the reason that the material trends toward the isotropy as the forming temperature increases.

Lue [4] recommended Eq. (1) for calculating the springback for plastic anisotropic sheets, which shows the relationship of the curvatures between before and after bending. As Eq. (1) shows, the springback reduces as the strength coefficient is smaller and elastic modulus is bigger. It implies that material properties such as sheet thickness, plastic anisotropy, strain hardening exponent, etc. affect the springback.

$$\frac{1}{R_c}-\frac{1}{R_c'}=K\left(\frac{1+\overline{R}}{\sqrt{1+2\overline{R}}}\right)^{1+k}\left(\frac{3(1-\nu^2)}{hE(1+n)}\right)\left(\frac{h}{2R_c}\right)^{k} \qquad (1)$$

where R_c and R_c' are radii of neutral surface of curved sheet before and after removing punch, respectively. K, $\overline{R}$, n, h, ν and E are respectively strength coefficient, plastic strain ratio, strain hardening exponent, specimen thickness, Poisson's ratio, and Young's modulus.

The reason why the springback reduces in high forming temperatures is inferred by the fact that the strength coefficient is smaller than other material properties like elastic modulus, strain hardening exponent, etc.

Figure 10 shows the comparison of springbacks in rolling direction between theory obtained from Eq. (1) and experiment. As the forming temperature increases, the trend of decrease in springback is the same between theory and experiment. They are agreed well each other although there are some deviations.

When AL1050 and AL5052 sheets are draw-bent in the forming temperature from room temperature to 350°C, the formed shapes of AL1050 and AL5052 after springback are shown in Fig. 11, respectively. As

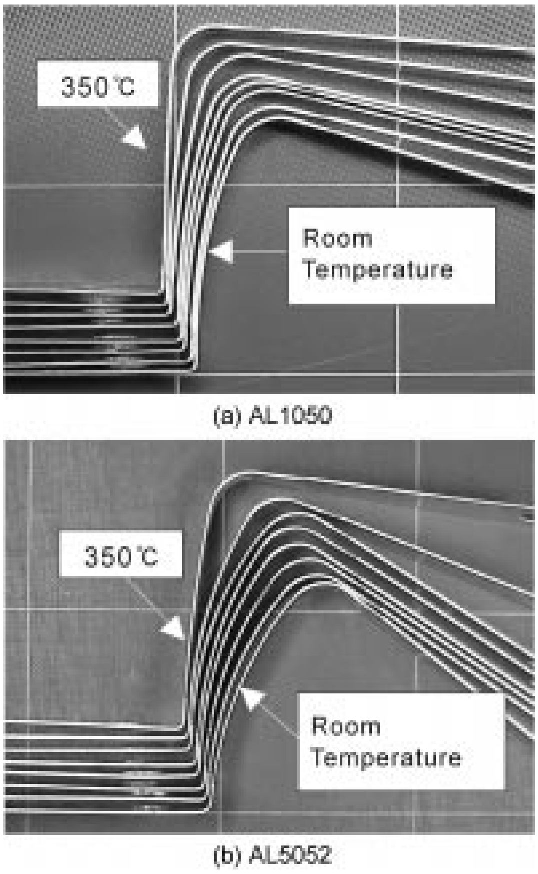

Fig. 11. Springbacks of (a) AL1050 and (b) AL5052 after draw bending test associated with test temperatures from room-temperature (R.T) to 350°C.

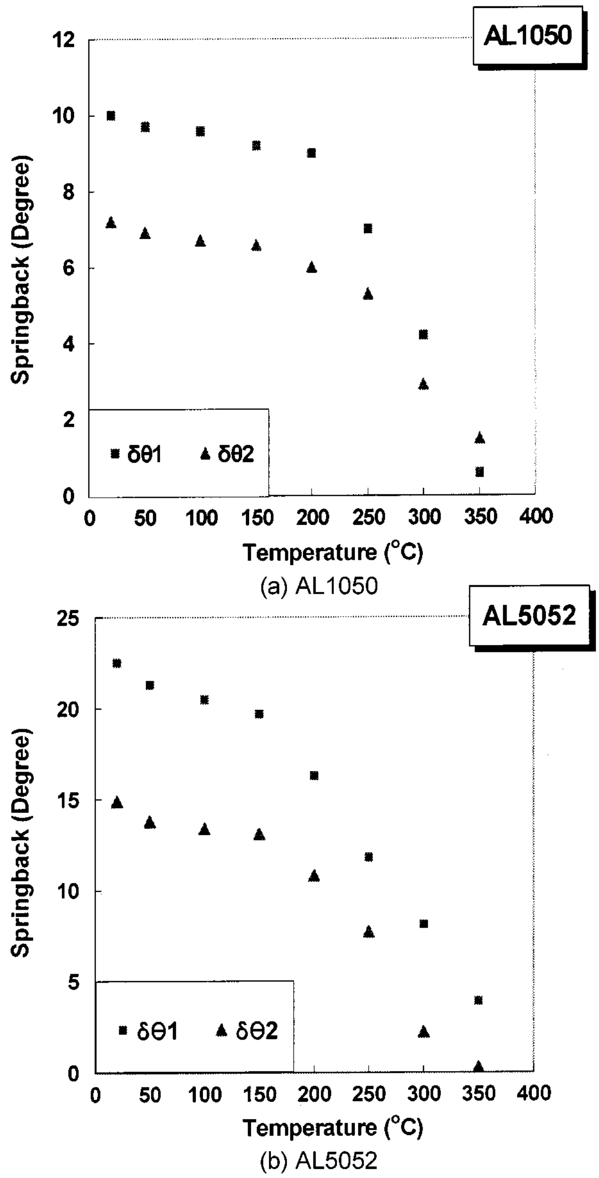

Fig. 12. Springback amounts of (a) AL1050 and (b) AL5052 after draw-bending test associated with test temperatures from room-temperature (R.T) to 350°C.

the forming temperature increases, the amount of the springback decreases, as seen in the stretch bending test.

Figure 12 numerically shows the springback amount measured in the draw bending test performed in various forming temperatures. Since the material properties in room temperature change as forming temperatures become high, the magnitude of the springback also changes in high forming temperatures, as seen in Fig. 12. AL1050 rapidly reduce springback from the forming temperature 250°C and AL5052 smoothly reduce springback from the forming temperature 150°C.

As in the stretch bending test, AL5052 sheet has bigger springback than AL1050 because the yield strength of AL5052 is bigger than that of AL1050. Furthermore, the reducing trend of springback is similar in both sheets and the reducing rate of AL5052 is bigger than that of AL1050. In draw bending test, $\delta\theta 2$ reduces the springback in lower temperature than $\delta\theta 1$.

Conclusion

In this study, the springback of aluminum alloys in warm forming conditions was investigated by performing the stretch as well as draw bending tests. Using the material properties obtained from the tensile test in high temperatures and the Lue's equation, the springback phenomena in high temperatures were qualitatively explained. Through this study, the following conclusions are derived:

(1) The warm forming temperature 150°C is a transition in terms of the material properties. Over the forming temperature 150°C, Yield strength, tensile strength, elastic modulus, strength coefficient, strain hardening exponent, etc. reduce but elongation and plastic strain ratio are increase. Below the forming temperature 150°C, the material properties show no big difference as the forming temperature changes.

(2) In the stretch bending test, the springback amount of AL5052 sheet is bigger than that of AL1050 and both sheets show a big reduction in springback over

warm forming temperature 150ºC.

(3) Lue equation provides a good estimation on the springback and agrees well with the experimental results.

(4) In the draw bending test, the springback rapidly reduces in the warming temperature 150ºC-200ºC for AL5052 sheets and 200ºC-250ºC for AL1050 sheets. AL5052 sheets also have more springback effect than AL1050.

Acknowledgments

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