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Processing Limit in V-bending

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V-bending is one of the most widely-used methods in sheet metal forming. Precise prediction of spring-back and precise control of punch stroke to obtain a target clamping angle are important to realize the manufacturing accuracy of bending angle in V-bend processing. Bottom bending which is one of the V-bending methods is often used for manufacturing applications requiring high accuracy, because of the slight spring-back and the stable clamping angle. This method is used for steel sheet metal. However it is rarely used for aluminum sheet metal, since precision requirement is not satisfied. In this research, it is clarified that the inadequate accuracy in bending angle in aluminum is caused by the processing limit that the minimum bending angle does not reach target angle. Therefore the control of minimum bending angle is important to solve the processing limit problem. The effect of tool parameters and mechanical properties of material on minimum bending angle is clarified using finite element method (FEM). As a result, the way to control the bending angle within the tolerance is proposed and confirmed experimentally.

Keywords: *bending, sheet metal forming, V-bending methods , spring-back, bottom bending, bending angle, processing limit.*

1. Introduction

Recently, increasing specific demands from customer include stricter accuracy prescriptions, a larger product variety and shorter delivery time. V-bending is one of the most widely-used methods in sheet metal forming. V-bending is flexible process by which a variety of different shapes can be produced with the use of simple and standard tools. Hence V-bending is suitable for a small batch manufacturing characterized with the wide variety of the products which have to be produced in small lot sizes. However it is necessary to adjust the working conditions to realize the manufacturing accuracy for each product. This adjustment is called “Trial Processing”, and leads to lower productivity. Therefore, “Trial Processing Free” that can obtain accuracy within tolerance without the adjustment is required.

Precise prediction of spring-back and precise control of punch stroke to obtain a target clamping angle are important to realize the manufacturing accuracy of bending angle in V-bend processing. Much research has been done to investigate and reduce the amount of spring-back [1, 2]. Bottom bending which is one of the V-bending methods is often used for manufacturing applications requiring high accuracy [3], because of the slight spring-back and the stable clamping angle. This method is used for steel. However it is rarely used for aluminum, since precision requirement is not satisfied in this method. In this research, FEM and experiments were carried out to clarify the reason of inadequate accuracy in bending angle in aluminum, and to propose the way to avoid it.

2. Experimental Procedures and Analytical Condition

2.1 Experimental Set-up and Methods

The work piece is bent by the punch in bending, and the state of work piece changes with increase of the punch stroke. Clamping angle started from 180º decrease with increase of punch stroke. When the load is removed, the work piece springs back a little and end up with less bend than that on the punch. Clamping angle θ_c, spring-back $\Delta\theta$ and bending angle θ_b is defined as shown in Fig.1. Air bending is a bending process which has 3 contact points to work piece at punch tip and die shoulders. Clamping angle becomes smaller than tool angle with increasing of punch stroke, then upper side of the work piece contacts to punch shoulder. There are contact points more than 5 at punch tip, die shoulders and punch shoulders, and it is called bottom bending. At the bottom bending, work piece is also bent at punch shoulders in the opposite direction to the bending at center. Then bending angle reaches target angle again in bottom bending.

The dimension of the punch and die are shown in Fig.2. Cold rolled steel (SPCC, JIS) and aluminum alloy (A5052, JIS) sheet with thickness t of 0.8, 1.0 and 1.2mm were used in experiment, and the sheet with thickness t of 1.0mm were used in FEM. The mechanical properties of material are summarized as shown in Table 1. Sheet metal has bending length l_0 of 100mm. Target bending angle φ is 90º and target tolerance of bending angle is ±0.25º.

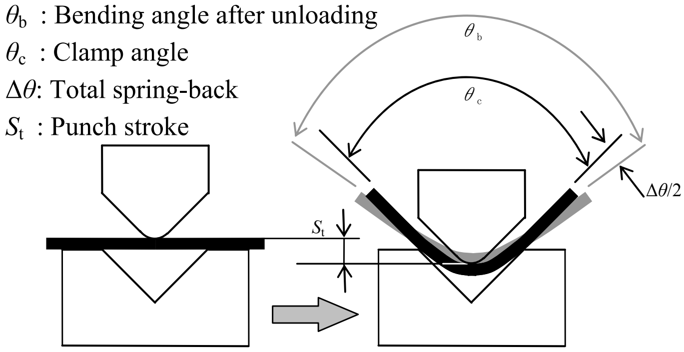


Fig. 1-Relation between clamping angle θ_c and bending angle after spring-back θ_b

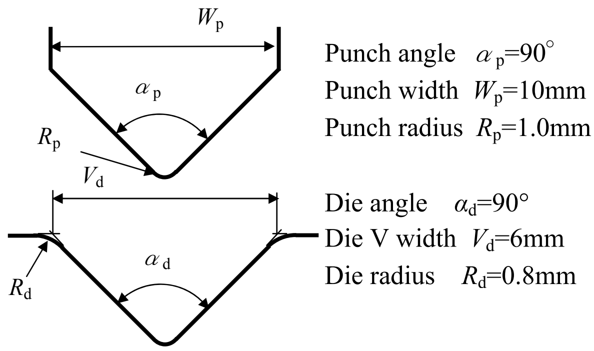


Fig. 2-tool geometry

Table 1-Mechanical properties of material

Material	Young's modulus E /Mpa	Yield Stress σ_Y /Mpa	Hardening coeffincient C /Mpa	Hardening exponent *n-value*
SPCC (JIS)	197311	209	576	0.20
A5052 (JIS)	74376	148	381	0.13

2.2 Analytical Condition

Finite element analysis was conducted using the commercial code ELFEN [4, 5], which was developed by Rockfield Software Limited. The implicit scheme is used in this research, in order to obtain the sufficient stability of solution and analytical accuracy. The FEA model is simplified to a 2D plane strain situation, because bending length l_0 of sheet metal is much larger than thickness.

3. Results and Discussion

3.1 Bottom bending in low carbon steel sheet metal

FEM simulation result shows clamping angle θ_c, bending angle after unloading θ_b and total spring-back $\Delta\theta$ attendant upon punch stroke S_t for low carbon steel sheet metal SPCC (JIS) as shown in Fig. 3. Fig. 4 shows the distribution of stress in tangential direction at (a) to (d) in Fig. 3. Fig. 4 (a) shows the state when the clamping angle is 90º. A small gap between punch shoulder and upper side of work piece is observed. Clamping angle becomes smaller than tool angle with increasing of punch stroke. When upper side of work piece contacts to punch shoulder as shown in Fig. 4(b), the clamping angle θ_c has a minimum value at (b) in Fig. 3 and bending state changes from air bending to bottom bending. At the bottom bending, work piece is also bent at punch shoulders in the opposite direction to the bending at center. Then the clamping angle reaches 90º again at (c) in Fig. 3. Spring-back is caused by the redistribution of stress that is compressive stress on upper side and tensile stress on lower side of work piece at zone A under the punch tip as shown in Fig. 4. Spring-forward is caused by the redistribution of stress that is tensile stress on upper side and compressive stress on lower side of work piece at the flange part zone B as shown in Fig 4. Total spring-back $\Delta\theta$ is the subtracted value from spring-back at zone A by spring-forward at zone B. Total spring-back $\Delta\theta$ decreases rapidly at (b) to (c) in Fig. 3, since spring-forward in zone B increases for the reversed bending. Bending angle has minimum value at (b) to (c) in Fig. 3. Contact point between punch shoulder and upper side of work piece changes from line contact to surface contact and moves to punch tip as shown in Fig. 4(c) to (d). The moving of this contact zone leads to decrease of zone B, then spring-forward decreases in zone B. Therefore, the negative value of total spring-back decreases at (c) to (d) in Fig. 3. The clamping angle at (c) to (d) in Fig 3 is almost same as tool angle and amount of its change is small. Then, bending angle reach 90º, which is target angle, at (d) in Fig. 3 in bottom bending area. At (d) in Fig. 3, the clamping angle is stabled at same angle as tool angle, and total spring-back is almost zero, because spring-back in zone A and spring-forward in zone B are almost same and the direction is opposite. As a result, the work piece can be bent with high accuracy in bottom bending than the air bending.

Fig. 5 shows the experimental result of bending angle whose target angle is 90º in SPCC (JIS), A5052 (JIS), with thickness t of 0.8, 1.0 and 1.2mm in bottom bending. While error angle is within the tolerance in SPCC (JIS), it is beyond tolerance in A5052 (JIS). The reason of the large error angle in A5052 (JIS) is investigated below.

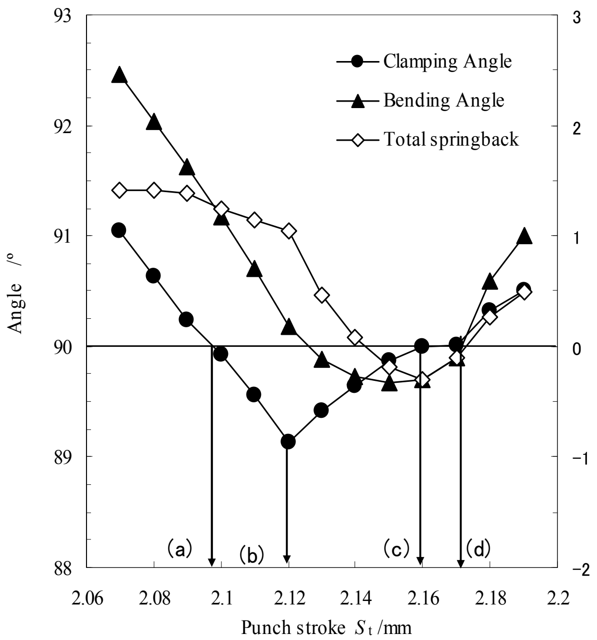
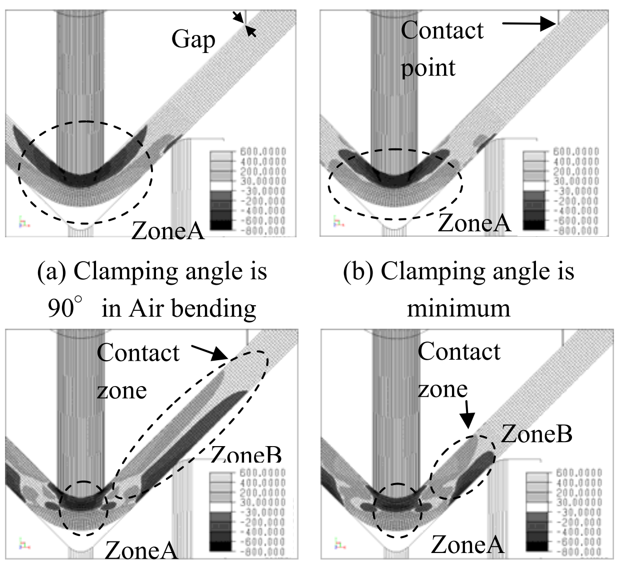


Fig. 3- Variation of clamping angle θ_c, bending angle after unloading θ_b and total spring-back $\Delta\theta$ attendant upon punch stroke S_t for SPCC (JIS)



(a) Clamping angle is 90° in Air bending

(b) Clamping angle is minimum

(c) Clamping angle is 90° in Bottoming

(d) Bending angle is 90° in Bottoming

Fig. 4-Stress status
(Alphabet of the figure corresponding to the state at (a) to (d) in Fig. 3)

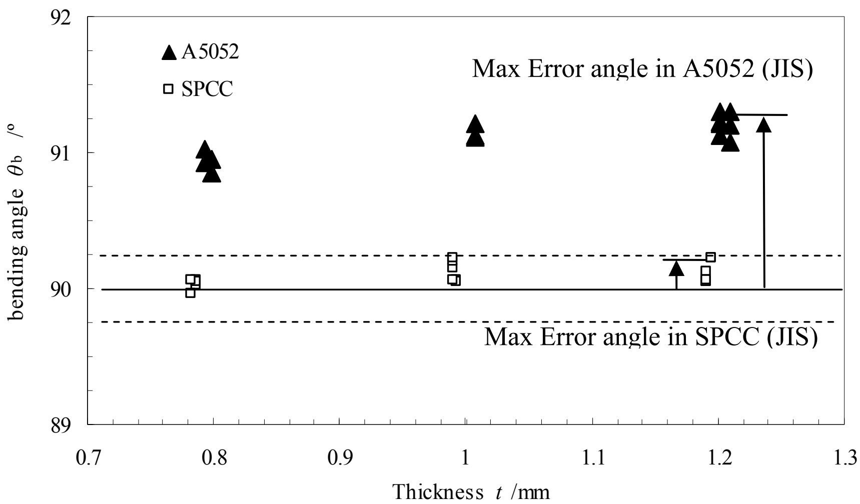


Fig. 5-Bending angle accuracy in bottom bending by experiment

3.2 Processing limit in Aluminum Alloy sheet metal

FEM simulation result shows clamping angle θ_c, bending angle after unloading θ_b and total spring-back $\Delta\theta$ attendant upon punch stroke S_t for aluminum alloy sheet metal A5052 (JIS) as shown in Fig. 6. The bending angle becomes minimum and its equals to 90.81º, when the punch stroke reaches 2.17mm. Here, the bending angle does not reach target angle even if the punch stroke adjust to any position. This phenomenon leads to error angle in A5052 (JIS) as shown in Fig. 5. It is necessary to control the minimum bending angle to be small to obtain a target angle.

In order to obtain smaller bending angle, effect of tool parameters and mechanical properties of material on bending angle is investigated. Bending angle are affected by work hardening exponent *n-value*, punch angle α_p, punch width W_p, punch radius R_p and die V-width V_d. Fig. 7 shows the influence of *n-value*, W_p, R_p and V_d on minimum bending angle using FEM. When the minimum bending angle is smaller than 90º, it is possible to bend to 90º, otherwise it can not be bent to 90º. Fig. 7(a) shows the amount of minimum bending angle decreases as the *n-value* increased. Thereby it is possible to control minimum bending angle by change in *n-value*. Fig. 7(b) shows the amount of minimum bending angle decreases as the punch radius decreases. Thereby it is possible to control minimum bending angle by punch radius. Fig. 7(c) shows the amount of minimum bending angle is not affected by punch width. Therefore it is hard to control the minimum bending angle by punch width. Fig. 7(d) shows the amount of minimum bending angle decrease as the die V-width increased. Thereby it is possible to control minimum bending angle by V-width. As a result, it is possible to control the minimum bending angle that is smaller than 90º by increase of *n-value*, decrease of punch radius or increase of V-width.

In this research, *n-value* is focused on and the effect of *n-value* on bending angle accuracy is confirmed experimentally. In order to obtain different *n-value*, A5052 (JIS) is annealed from 300 to 380 ºC [6]. Mechanical properties of annealed material are shown in Table 2. Variation of *n-value* in annealed materials is shown in Fig. 8. The *n-value* increases form 0.15 to 0.3 at the annealing temperature of 300 to 340 ºC. Fig. 9 shows the experimental result of bending angle whose target angle is 90º with thickness t of 0.8 and 1.0mm in bottom bending. It shows the error angle decreases as the *n-value* increases. Error angle is successfully suppressed within the tolerance of ±0.25º by subjecting A5052 (JIS) to annealing at temperature from 320 to 380 ºC, whereby *n-value* is much larger than original value. Fig. 7(a) shows if *n-value* is more than 0.25, it is possible to bend in bottom bending. The result of experiment as shown in Fig. 9 verifies this assumption.

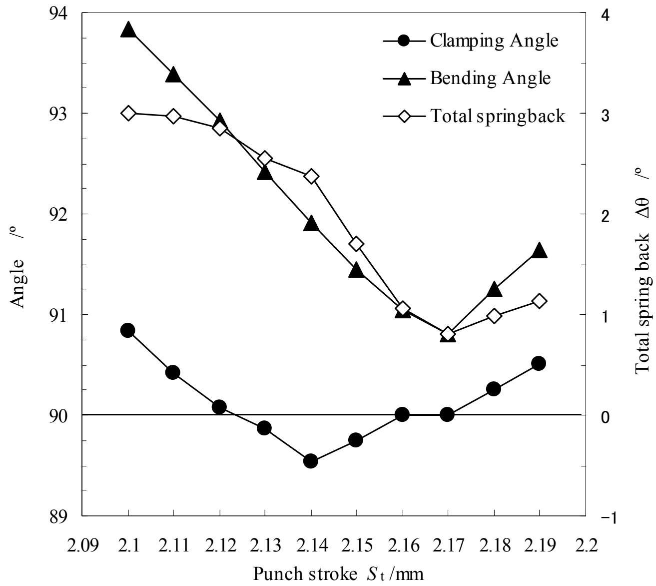
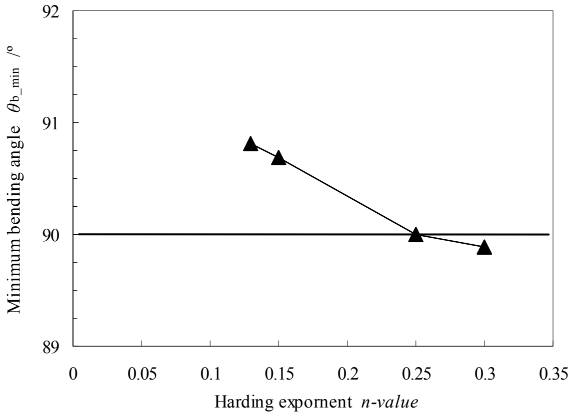
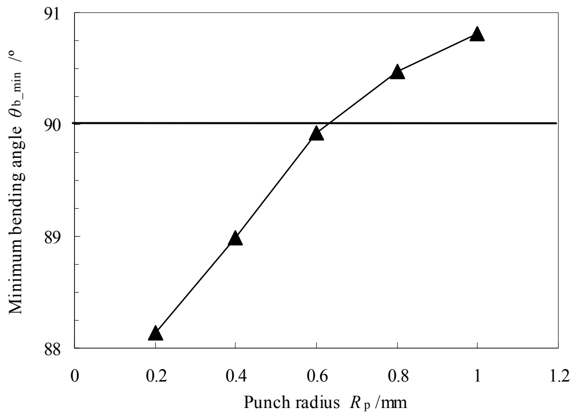


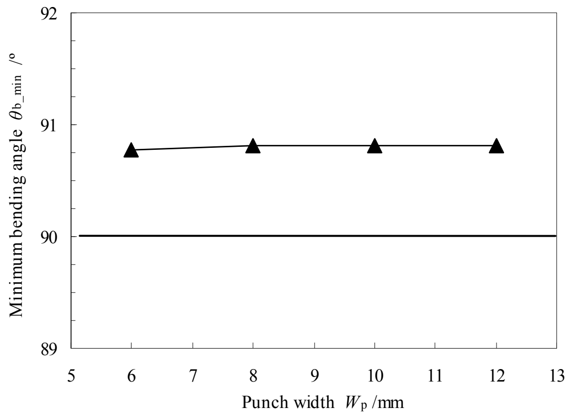
Fig. 6- Variation of clamping angle θ_c, bending angle after unloading θ_b and total spring-back $\Delta\theta$ attendant upon punch stroke S_t for A5052 (JIS)



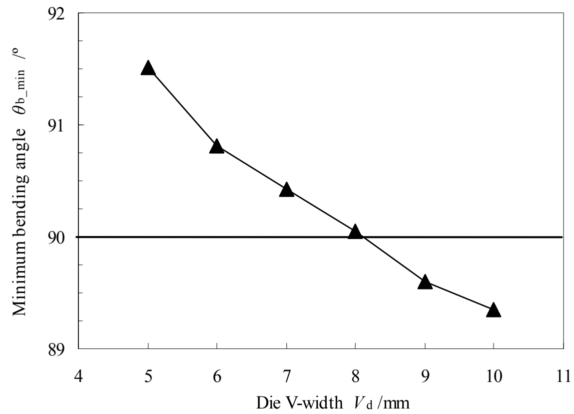
(a) n-value



(b) Punch raduis



(c) Punch width



(d) Die V-width

Fig. 7-Variation of minimum bending angle θ_b with respect to each parameter by FEM

Table 2-Mechanical properties of material

Material	Young's modulus E /Mpa	Yield Stress σ_Y /Mpa	Hardening coeffincient C /Mpa	Hardening exponent n
A5052	74376	148	381	0.13
A5052_300 ºC	70903	154	380	0.15
A5052_320 ºC	74252	98	402	0.25
A5052_340 ºC	70416	100	412	0.30
A5052_380 ºC	74437	91	398	0.30

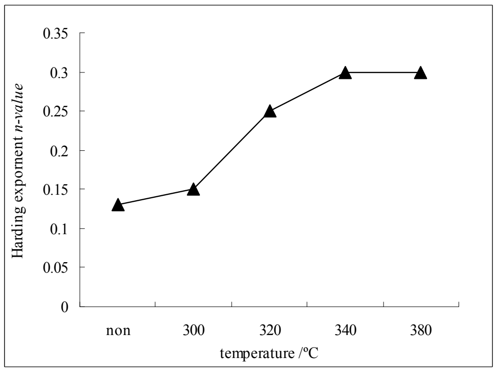
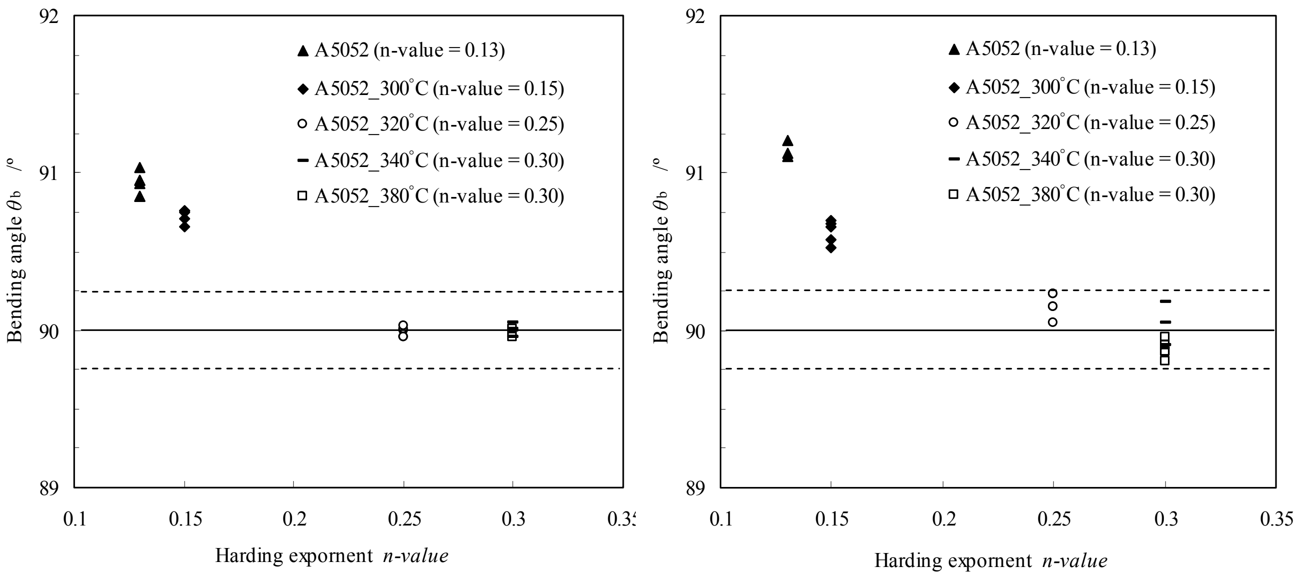


Fig. 8- Variation of n-value



(a) Thickness t = 0.8mm

(b) Thickness t = 1.0mm

Fig. 9- Effect of *n-value* on bending angle in bottom bending by experiment

4. Conclusion

The reason of the inadequate accuracy in bending angle in aluminum is caused by the processing limit that the minimum bending angle does not reach target angle. It is possible to control the minimum bending angle to get target angle by increase of *n-value* or decrease of punch radius or increase of V-width. It is confirmed experimentally that the error angle becomes small within tolerance to change n-value to anneal A5052 (JIS) at the temperature of 320 to 380 ºC.

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