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Stretch press bending of AZ31 magnesium alloy extruded square tube

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Abstract

The results of the experimental study on bending behaviour of AZ31 magnesium alloy extruded square tube under stretch press bending are presented. Cracking with buckling occurs at compressive side, but we can bend AZ31 tube at room temperature by means of applied axial tension during forming. The mechanism of bending behaviour of AZ31 magnesium alloy tube has been examined from the point of view of the position of neutral axis according to the mechanical properties under tension and compression and flow stress dependency on strain rate.

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Keywords: AZ31 magnesium alloy extruded square tube; Press bending behaviour; Room temperature; Dependency on strain rate

1. Introduction

In transportation systems, light metals that can be easily recycled must be used for the weight reduction of automotive outer panels, energy absorption structures, suspension parts, and so on. As an example, magnesium alloys are used for parts of the steering wheel, instrument panel, and seat structure. In order to use lightweight bent tubes in transportation systems, we have studied methods that prevent cracking, buckling, and cross-sectional distortion under press bending in 6000 series aluminum [1] and AZ31 magnesium alloy extruded tubes [2]. In this study, a bendability improvement method for the press bending of AZ31 magnesium alloy extruded square tube is presented. We have applied wing-type dies [3] to stretch press bending, which can restrain cracking at the

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compressive side with axial tension [4]. Furthermore, we have confirmed the effect of high strain rate on the bendability of AZ31 tube.

Nomenclature

R_p	Punch profile radius
R_0	Bending radius
H_0	Height of cross-section of tube
W_0, W_1	External and internal width of cross-section of tube
t_0	Initial thickness of tube
t_t ,t_c	Outside and inside thickness of tube after bending
t'	$(t_t - t_c)/2$
n	Strain hardening exponent
σ_t , σ_c	Average flow stress of tension side and of compression side
m	Ratio of axial tensile stress to tensile strength of tubes (based on nominal stress)
δ	Position of neutral axis in the cross-section at bending centre of tube
y	Co-ordinate for the height of cross-section of tube

2. Experiment

2.1. Material

Two kinds of AZ31 magnesium alloy square tubes, which were extruded under different billet temperatures (623 K and 723 K), were used. In this paper, they are referred to as TP350 and TP450, respectively. The cross-sectional shapes and dimensions are shown in Fig. 1.

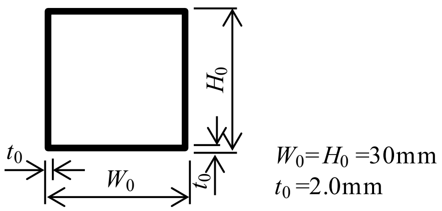

Fig. 1. Cross-sectional shape and dimensions of square tube.

2.2. Tension and compression test

Tension tests were performed in the room temperature with JIS13B test pieces. The n-value was derived at a strain range from 0.02 to 0.03. Compression tests were performed with test pieces that were cut from a square tube and finished with parallel end surfaces by a milling machine. The cross-head speeds were 5 and 500 mm/min in both tension and compression tests for the investigation of the strain rate effect. Before the high strain rate compression test, there was a gap of over 20 mm between the compression tool and the test piece.

2.3. Press bending experiment

The bending dies are shown in Fig. 3. They were set on a 350 kN capacity press machine. Bending is executed at room temperature. Bending conditions are shown in Table 1. Wing-type dies were used, which had their positions of support (i.e., the distance between the support plane of the tube and the rotational support of the wing) designed to obtain about 3% strain in the length of the 350 mm region of the square tube.

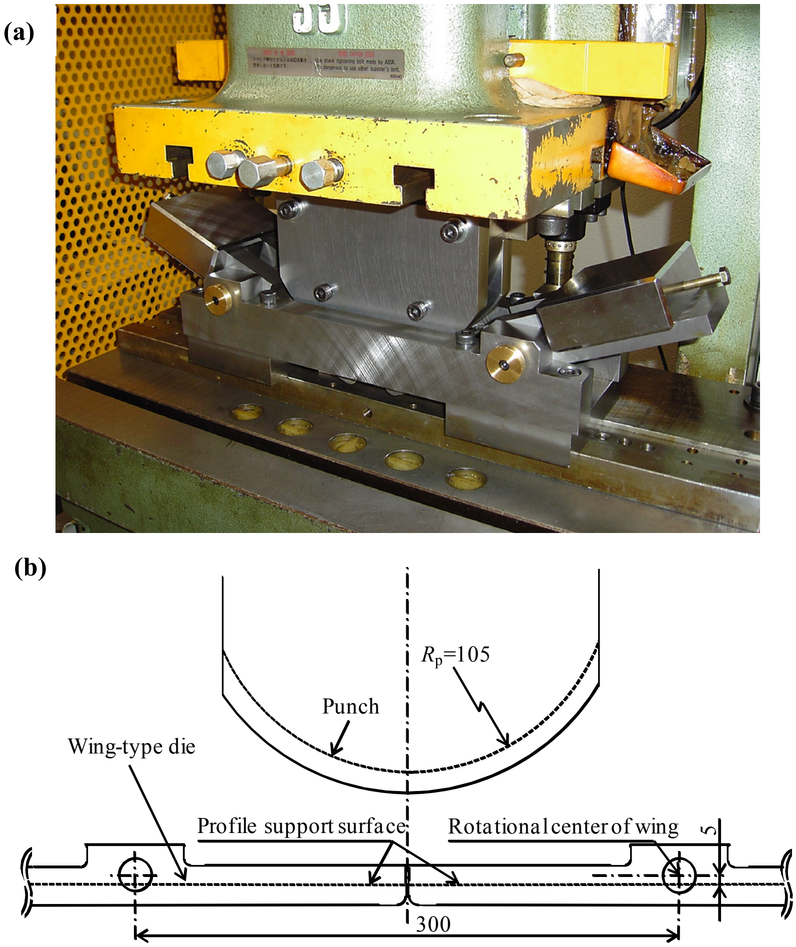

Fig. 2. Press bending setup. (a) Appearance of bending die at lower dead point and (b) main parts and dimensions of tooling.

Table 1. Bending conditions.

Punch stroke per minute (spm)	60
Punch profile radius R_p (mm)	105
Bending radius R_0 (mm)	120
Ratio of bending radius and profile height R_0/H_0	4.0
Target bending angle (degree)	45
Total clearance between die and material (mm)	0.5
Kinematic viscosity of lubricant on punch and dies (mm^2s^{-1})	630
Temperature	R.T.
Internal mandrel	without

3. Experimental results

3.1. Material

Mechanical properties of material derived from tension and compression test are shown in Table 2. There is no different between TP350 and TP450 remarkably, but strength factor of TP350 is slightly higher than TP450. Under high strain rate, both of materials have higher tesile proof stress and compressive maximum stress. As a result, they have higher average flow stress in the compressive side under high strain rate. Apperance of specimens after tests are displayed in Fig. 3.

Table 2. Mechanical properties of material used.

tension (JIS13B)

specimen	Cross head speed $(mm \cdot min^{-1})$	n^* value	F^* Value (MPa)	Proof stress $\sigma_{0.2}$ (MPa)	Tensile strength σ_B (MPa)	Average flow stress $\bar{\sigma}_t$ (MPa) (strain range)	Breaking Elongation (%)
TP350	5	0.12	330	190	230	240(ε:0～0.17)	17
	500	0.08	300	210	230	240(ε:0～0.17)	18
TP450	5	0.12	330	180	220	240(ε:0～0.18)	18
	500	0.08	300	210	230	240(ε:0～0.17)	18

compression

specimen	Cross head speed $(mm \cdot min^{-1})$	Proof stress $\sigma_{0.2}$ (MPa)	Maximum stress σ_{MAX} (MPa)	Average flow stress $\bar{\sigma}_c$ (MPa) (strain range)	Strain at maximum stress** (%)
TP350	5	90	240	120 (ε:0～0.11)	11
	500	100	270	130 (ε:0～0.11)	12
TP450	5	90	230	110 (ε:0～0.11)	11
	500	90	260	140 (ε:0～0.12)	11

$^*\sigma = F\varepsilon^n$, **G.L.=25mm

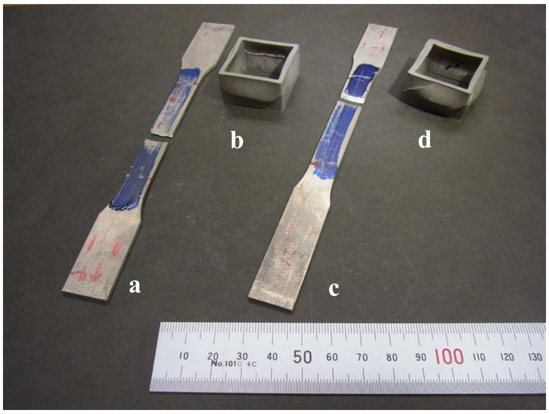

Fig. 3. Appearance of specimens after tests. (a) TP350 tension, (b) TP350 compression. (c) TP450 tension and (d) TP450 compression.

3.2. Press bending

The appearances of the AZ31 alloy square tubes after press bending are displayed in Fig. 4. In the photograph, (a) and (c) are bent tubes of the same bending radius (R_0=120 mm) and target bending angle (45 degrees) under three-point press bending without axial tension. By applying axial tension, cracks are prevented from occurring on the compressive side ((b) and (d)). However, since a mandrel was not used, buckling (i.e., wrinkling on the compressive flange) and sagging (on the tensile flange) did occur.

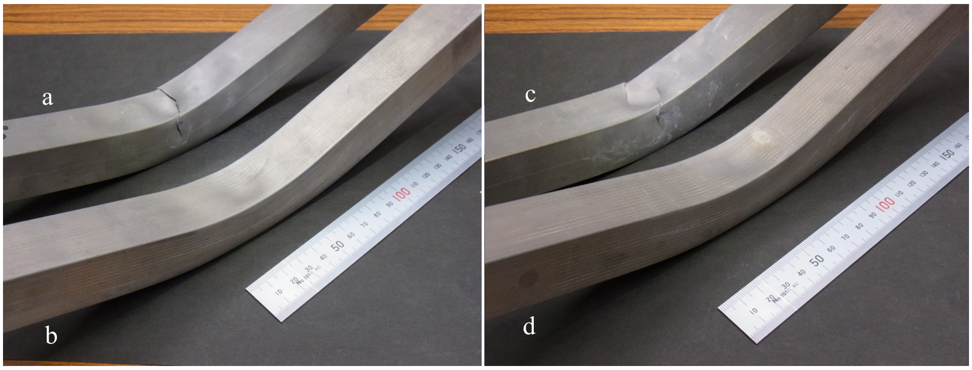

Fig. 4. Appearance of specimens after press bending. (a) TP350 without axial tension, (b) TP350 stretch bending, (c) TP450 without axial tension and (d) TP450 stretch bending.

4. Discussion

It is known that the neutral surface shifted toward the tensile side after bending because the tensile and compressive flow stresses and strains at the compressive side increased, and therefore, cracking occurred on the compressive side [4]. From the results of this study, it has been clarified that cracking was restrained by means of axial tension because of the tendency of the neutral surface position to shift toward the compressive side and the decrease in the compressive strain level in the press bending of AZ31 square tube.

If the neutral surface shifted a distance δ from the initial position, which is the centroid of the cross section, then δ can be expressed theoretically using the following formula based on the equilibrium forces at the cross section of the square tube. It is assumed that thickening and thinning of wall occur only at compressive flange and at tensile flange each other.

$$\delta = \frac{1}{\overline{\sigma_t} + \overline{\sigma_c}} \left\{ \left(\overline{\sigma_t} - \overline{\sigma_c} \right) H_0 / 2 + \left(\overline{\sigma_t} t_t - \overline{\sigma_c} t_c \right) W_1 / 2t_0 - m\sigma_B \left(H_0 + W_1 \frac{t_t + t_c}{2t_0} \right) \right\} \quad (1)$$

The coefficient m is the ratio of tensile stress to tensile strength of the material. We substitute each value to the formula (1), when m=0.45, t_t=1.9 and t_c=2.1, we can obtain value, δ = -11. The absolute value is too large, but we can confirm the tendency of the neutral surface position to shift considerably toward the compressive side, against δ=7 (experimental value is 5) under m=0, without axial force.

5. Conclusions

We can bend AZ31 magnesium alloy extruded square tube without cracking by means of stretch press bending applying wing-type dies under bending conditions of room temperature and R_0/H_0 = 4.0. The mechanisms of bendability enhancement are listed as follows.

(1) AZ31 alloy has relatively high compressive flow stress under high strain rate.

(2) There is the tendency that the neutral surface position is shifted toward the compressive side by the flow stress, thickness deviation of cross section and the axial tension.

References

[1] O. Hasegawa, H. Nishimura: Improvement methods of bending accuracy for 6000 series aluminum alloy extruded shapes in press bending, Proc. ICAA7 (2000), 577-582.
[2] O. Hasegawa, K. Manabe, N. Inoue, H. Nishimura: Effect of forming temperature on press bendability of AZ31 magnesium alloy tube, J. JSTP, 48-556 (2007), 422-426 (in Japanese).
[3] O. Hasegawa, K. Manabe, H. Nishimura: Effect of wing-type die in Press bending of aluminum alloy extruded shapes, J. JILM, 57-6(2007), 245-249 (in Japanese).
[4] O. Hasegawa, K. Manabe, T. Murai, H. Nishimura: Proc. 62nd JSTP (2011), 325-326 (in Japanese).