고온에서의 AZ31 마그네슘 합금 경화 모델과 V-굽힘의 예측을 위한 수정된 경화거동

Modified Hardening Behavior to Predict V-Bending Spring-back of AZ31 Magnesium Alloy Sheet at Elevated Temperatures

*누엔늑뚜안 [1], #정동원 [1], 김동홍 [1], 김봉천 [1], 김영석 [2]

*Nguyen Duc-Toan[1], #Jung Dong-Won (jdwcheju@jejunu.ac.kr)[1], Kim Dong-Hong[1], Kim Bong-Chun[1], Kim Young-Suk[2]

[1] 제주대학교 기계공학과, [2] 경북대학교 기계공학과

Key words : AZ31 sheet, (J-C) model, Hardening model, FEM, spring-back prediction

1. Introduction

AZ31 magnesium alloy sheets is usually performed at elevated temperatures of 200℃ to 250℃ due to the unusual mechanical behaviour of its hexagonal close-packed structure and low ductility at the room temperature. Nowadays, researches on magnesium alloy have increased and as an extension, many papers have been made based on elevated temperature magnesium alloy sheet metal forming [1]. Previous studies proposed hardening models to predict correctly stress-strain curves and then applied to predict spring-back in sheet metal bending process using shell elements [2]. However, because of compression-tension and tension-compression phenomenon occur at the same time for these processes then shell elements could not verify and investigate the spring-back of bending process exactly.

In this study, In order to predict V-bending/unbending spring-back for AZ31 magnesium alloy sheet at elevated temperatures, a modified kinematic/isotropic hardening model considered the unusual plastic behaviour by describing the scalar parameter β as a function of equivalent strain when compressive and reverse stress concurrency was carried out via a user-material subroutine, using explicit finite element code. First, the simulation results at room temperature were presented and compared with measurements of tension-compression, compression-tension test for the modified hardening model. A modified Johnson-Cook (J-C) model was then applied to predict tension/compression and compression/tension curves at elevated temperatures. Finally, the V-bending/unbending process for AZ31 magnesium alloy sheet at elevated temperatures was performed in order to verify spring-back angle and then compared with spring-back angle predictions of FE simulation results. The proposed hardening model showed good agreement between simulation results and corresponding experiments

2. Material and hardening model

Uni-axial tensile tests were first conducted at temperatures for 1-mm-thick AZ31 sheet. To fit stress-strain curves, Ludwick's hardening law Eq. (1) is implemented to determine hardening parameters which were listed in table 1. Figure 1 also depicts the fitting curves at elevated temperatures.

$$\bar{\sigma} = \sigma_Y + F(\varepsilon_{eq}^{pl})^n \qquad (1)$$

where F is the plastic coefficient, n is the work-hardening exponent, and $\bar{\sigma}, \varepsilon_{eq}^{pl}$, and σ_Y are the equivalent stress, equivalent strain, and tension yield stress, respectively.

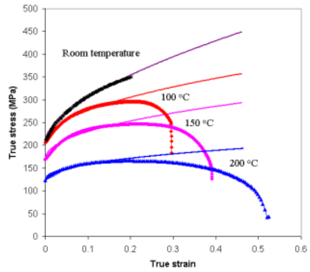

Fig. 1 Stress-strain curves predictions

Table 1 Hardening parameters at elevated temperatures determined by fitting curves

	Ludwick's hardening law		
Temperature	σ_Y	*F*	*n*
24°C	210	382.498	0.606
100 °C	205	224.031	0.499
150 °C	168	178.834	0.462
200 °C	124	97.258	0.444

Even though stress-strain curve of textured magnesium alloys was observed asymmetric, the Von-Mises model based on Combined hardening model can be assumably applied in calculation for separated tension and compression zone.

The incremental analogs of the rate equation are shown by Eqs. (2)~(4):

$$\sigma_{ij}\Big|_{n+1} = \sigma_{ij}^{tr}\Big|_{n+1} - 2\mu\Delta\gamma Q_{ij} \tag{2}$$

$$R\Big|_{n+1} = R\Big|_{n} + \frac{2}{3}\beta H\Delta\gamma \tag{3}$$

$$\alpha_{ij}\Big|_{n+1} = \alpha_{ij}\Big|_{n} + (1-\beta)\frac{2}{3}\Delta\gamma H Q_{ij} \tag{4}$$

where $\sigma_{ij}, R, \alpha_{ij}, Q_{ij}$ are the current stress, radius of yield surface, back-stress, normal of yield surface, *H*, the slope of the effective stress versus the plastic strain curve. The scalar parameter $\beta = 0$ corresponds to only pure kinematic hardening occurs, $\beta = 1$ to only pure isotropic hardening, and $0 < \beta < 1$ in the case of combined hardening. After solving, $\Delta\gamma$ will be obtained:

$$\Delta\gamma = \frac{1}{2\mu\left(1+\frac{H}{3\mu}\right)}\left((\xi_{ij}^{trial}\,|_{n+1} : \xi_{ij}^{trial}\,|_{n+1})^{1/2} - R_n\right) \tag{5}$$

For AZ31 sheet, we presented β as functions of equivalent strain then we could predict correctly the shapes of stress-strain curves at compression and reverse stress as shown in Fig. 2.

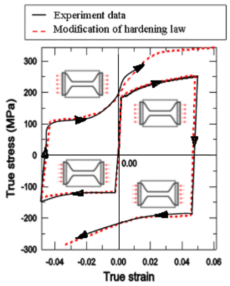

Fig. 2 Experiment and FE simulation results

3. V-bending/Unbending spring-back prediction

Our proposed hardening model was applied for V-bending/Unbending spring-back prediction at room temperature and then combined with modified J-C model to predict spring-back at elevated temperatures as shown in Fig. 3, 4.

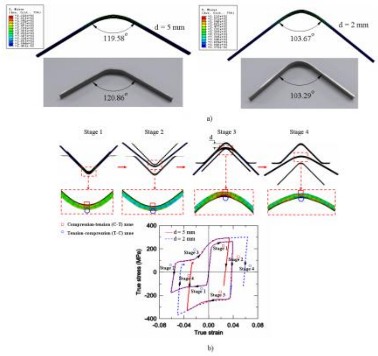

Fig. 3 V-bending/unbending predictions

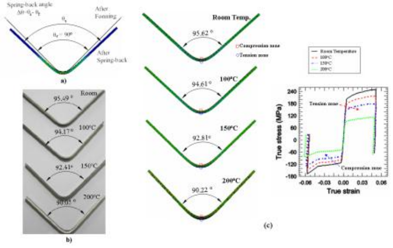

Fig. 4 V-bending predictions at elevated temperatures

4. Conclusion

In order to predict correctly spring-back of bending process for AZ31 magnesium alloy sheet, the stress-strain curves at tension and compression zones must be represented accurately.

Acknowledgments

This work was supported by the research grant of the Jeju National University in 2008

References

1. E. Doege, K. Droder, Processing of magnesium sheet metals by deep drawing and stretch forming, *J. Mat. Proc. Tech.*, 7-8 (1997), 19–23.
2. M.G. Lee, S.J. Kim, R.H. Wagoner, K. Chung, H.Y. Kim, Constitutive modeling for anisotropic/asymmetric hardening behavior of magnesium alloy sheets: Application to sheet springback, *Int. J. Plast.*, 25 (2009), 70-104.