Influencing Variables of Drawing Process using Magnesium Tubes

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Abstract: The present work examines the deformation of magnesium tubes using drawing process. During examination, absence of wrinkling and cracking is witnessed at 303k. The effect of mandrel on the cross section of the extruded tubes, wall thickness and spring-back of the bent tube are vividly discussed. Results show that presence of mandrel decreases the cross section of distortion and the spring back angle. Further, the present investigation clarifies the thinning rate of tube wall thickness. It is found that at the bending angle of 90° largest distortion is witnessed.

Keywords: Drawing Process, Deformation Mechanism, Extrusion, Magnesium Tubes

I. INTRODUCTION

Evolution of engineering materials provides the way for sustainable development in the domain of manufacturing industries such as aerospace, automotive etc. Among the various mechanical properties, Materials with ductility is more suitable for manufacturing process in general, tube drawing process in particular. To carry out Rotary Tube Drawing (RTB) process, magnesium alloy has been chosen as it prone to produce product with defects-free than steels and aluminum alloys. On the other hand, the cold workability of magnesium is poor because of a close-packed hexagonal (HCP) crystal structure [3]. While carrying out tube-bending, few shortcomings hinder the application of magnesium alloys as structural components [4]. The material design, fabrication, and processing of magnesium alloy should be improved to accelerate the application of magnesium alloy. With the mature of material design and fabrication, the magnesium alloy forming process becomes a hot point of researching.

Rotary draw bending (RDB) is a forming process in which the metallic tube is drawn and rotated around the bending die. It is widely applied in the processing of a variety of thin-walled tubes because of its high forming precision, high efficiency, good bending quality, and easy automation. During the RDB, forming defects such as cross-section distortion, wrinkling, wall-thickness thinning (even cracking) and spring-back may appear due to inhomogeneous tensile and compressive deformations at the extrados and the intrados of the bent tube [5].

In this paper, the RDB process of circular extruded tubes of magnesium alloy Mg-7Al-0.5Zn was investigated. The influences of the mandrel on the cross-section distortion, wall-thickness variation and spring-back of magnesium alloy tube were analyzed and discussed.

II. EXPERIMENT PROCEDURES

A. Material

The material under investigation was magnesium alloy Mg-7Al-0.5Zn, containing rare earth elements of La and Gd. The magnesium alloy was hot extruded into circular tubes at the initial billet temperature 250 °C, extrusion ratio 68 and extrusion speed approximate 20mm/s. Figure 1a shows the cross-section dimensions of the extruded circular tube, where the outer diameter was 17 mm and the wall-thickness was 1 mm. The bent profile is schematically shown in Figure 1b, in which the bending radius is 90 mm and the bending angle is 90°.

![Fig. 1. Dimensions of (a) cross-section and (b) bent outline of magnesium alloy extruded tube.](image)

B. Bending experiment

Figure 2 shows the RDB tooling of circular magnesium alloy tube, including insert die, bending die, pressure die, wiper die, clamp die and mandrel. During the Bending, bending die is driven by the spindle to rotate at a given angular velocity. One end of the extruded tube is constrained on bending die by clamp and insert die. The rest of the tube is arrested by pressure die, wiper die, and mandrel.

The clamped tube rotates to certain angle such that the bending dies are rotated. During the tube bending, the pressure dies moves forward with the tube feeding at a certain speed to reduce the friction force and wiper die remains stationary.

Rotary draw bending experiments were carried out on a numerical control tube bender at room temperature. In order to analyze the influence of the mandrel on the forming quality of magnesium alloy, the tube bending experiments with and without mandrel were tried out. The process parameters of the RDB of the magnesium alloy tube are listed in Table 1.
C. Shape distortion

The paramount importance of variable is used to ascertain the accuracy of the bent tube are the rate of change of diameter, the thickness of tube wall and rate of thinning and the spring-back angle.

**TUBE DRAWING**

Fig. 2. Tooling of the RDB of magnesium alloy tube.

The diameter change rate $L_d$ is defined as

$$ L_d = \frac{\text{Initial Diameter - Vertical Diameter after Bending}}{\text{Initial Diameter}} \times 100\% $$

(1)

The thinning of tube wall at the extrusion leads to a strength weakening of circular tube during the bending process. The variation in thickness is generally followed to measure the tube wall thinning and thickening degree and is defined quantitatively by

$$ \frac{\text{Wall thickness}}{\text{Tube Wall thickness - Minimum Wall thickness}} \times 100\% $$

(2)

Where, $T$ and $T_{min}$ are the tube wall thickness before bending and the minimum one after bending, respectively.

Due to the effect of the spring-back of metallic materials, the actual bending angle of the bent tube is less than the predetermined one. The spring-back angle is expressed as

$$ \Delta \theta = \theta - \theta' $$

(3)

where, $\theta$ and $\theta'$ are the bending angles predetermined and after spring-back, respectively.

| Table-1: Variable Parameters of rotary magnesium tube |
|--------|--------|--------|
| **S. No** | **Variables** | **Values** |
| 1      | Bending Angle | 90° |
| 2      | extrusion speed | 20 mm/Sec |
| 3      | Wall thickness | 1 mm |
| 4      | Initial Tube Temperature | 250 °C |

III. RESULTS AND DISCUSSION

The magnesium alloy under investigation possesses favorable mechanical properties at room temperature. The cracking and wrinkling were not found in the bent tubes, indicating the good cold workability of the investigated magnesium alloy. During the magnesium alloy tube bending, it is prone to result in forming defects such as outer wall thinning, inner wall thickening, cross-section distortion, and spring-back, degrading the performance of the bent tubular parts. The application of mandrel in tube bending can partly eliminate or weaken these forming defects [6]. The mandrel influence on the forming quality of the bent tube of magnesium alloy was analyzed.

A. Cross-section distortion

Figure 3 shows the half split tubes that were bent with a bending angle of 90°, where the deformed cross-sections can be found. The largest distortion occurred in the position approximate 30° far from clamp die. Figure 4 demonstrates that the distribution of the diameter change rate along the tubing elbow, where ten positions were selected every an angle of 10°. The maximum value of outer diameter change rate of circular tube bent without mandrel was approximately 7.5%, while the corresponding value of the tube bent with mandrel was less than 5.0%. It indicated that the mandrel played an important role in weakening cross-section distortion of magnesium alloy tube [7]. It shows that the diameter change rate decreased with increasing distance (angle) from the clamping end of the bent tube. This was because the mandrel length was limit and has little supporting effect at the clamped end of the tube.

Fig. 3. Split magnesium alloy tubes bent

B. Tube wall thinning

Figure 5 shows the tube wall thinning rate distribution at the extrados [8] along the angle from the clamped end of the tube to the position close to wiper die. With increasing distance (angle) from the clamped end of the tube, the wall thinning rate first rose and then fell, that is, the middle of the tubing elbow was more thinned than both ends. It can be found that the wall thinning rate of the tube bent without mandrel was lower than that bent with the mandrel [9]. The maximum wall thinning rate of the tube bent with mandrel was 14.0% compared with that of 12.1% without the mandrel. Bending without mandrel reduced the tube wall thinning rate at the extrados, but also exacerbated the thickening of the tube wall at the intrados and even contributed to the occurrence of wrinkles. The tube wall thickness deformation began to decrease gradually at a distance close to both ends of the tubing elbow. While the straight section of tube that did not participate in the bending deformation also underwent a certain wall thickness deformation, which indicated the straight tube section absorbed and alleviated local deformation in the bending area.

Fig. 4. Diameter change rate.
Fig. 4. (a) Measured positions, (b) diameter change rate varying with positions.

In order to analyze the variation of the tube wall thickness at the cross-section, it was measured at sampling positions every 30 degrees along the circumference. Measurement results are shown in Figure 6, the staring measured point is at the top of the extrados. It indicated that the tube wall-thickness varied with the position along the cross-section circumference of the circular tube. At the top of the extrados, the maximum thickening rate appeared, and the maximum thinning rate at the middle of the intrados.

Fig. 5. Wall thinning rate distribution of the tube

Fig. 6. Distribution of wall thickness along the circumferential section of bent tube at the 45°

C. Spring-back

Figure 7 shows the spring-back angle versus the bending angle curve of the magnesium alloy tube. RDB experimental results showed that the spring-back angle increased approximately linearly as the bending angle increased. The spring-back angle in the mandrel bending was smaller than that in the mandrel-free bending [10]. The magnitude of the spring-back angle depended mainly on the elastic strain energy stored inside the bent tube wall during the deformation process [11, 12]. The greater the elastic strain energy stored in the tube wall, the larger the spring-back angle after the tube bending. Bending with mandrel weakened the elastic strain energy, resulting in a smaller spring-back angle.

Fig. 7. Spring-back angle versus bending angle curve of magnesium alloy tube.

IV. CONCLUSION

The rotary draw bending of the extruded tube of magnesium alloy was presented. At room temperature, the tubes were bent without cracking and wrinkling, but the shape distortions were inevitable. The shape and dimension precisions of bent tubes were analyzed, including the diameter change rate, the tube wall thinning and thickening rate and the spring-back angle. The influences of the mandrel on the shape distortion were analyzed.

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