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Study on Hydroforming of Magnesium Alloy Tube under Temperature Condition

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Abstract. First of all, under 100 ℃, 150 ℃, 200 ℃, 250 ℃, 300 ℃ and 350 ℃, respectively do the test of magnesium alloy AZ31B temperature tensile and the fracture of SEM electron microscopic scanning, studying the plastic forming ability under six different temperature. Secondly, observe and study the real stress-strain curves and fracture topography. Through observation and research can concluded that with the increase of temperature, the yield strength and tensile strength of AZ31B was increased, and the elongation rate and the plastic deformation capacity are increased obviously. Taking into account the actual production, energy consumption, and mold temperature resistance, 250 ℃was the best molding temperature. Finally, under the temperature condition of 250 ℃, the finite element simulation and simulation of magnesium alloy profiled tube were carried out by Dynaform, and the special wall and forming limit diagram of magnesium alloy were obtained. According to the forming wall thickness and forming limit diagram, the molding experiment can be optimized continuously.

1. Introduction

Hydroforming is a kind of forming method which utilizes the high pressure of liquid to make the tube billet bulging out different shape characteristic parts [1]. Hydroforming is mainly used for the forming of pipe fittings (round pipe, square, shaped tube, etc.), and the corresponding internal high-pressure forming equipment including mold, push device and hydraulic device. When machining, put the mold cavity part of the lower mold into the tube billet, and placed the upper mold to confine the tube blank in the cavity. And then, at each end of the tube billet, a pushing head, providing the axial force of the tube, is provided with the corresponding ends of the tube billet, which is used for feeding. And then put the inside of high-pressure liquid into the tube billet to provide the forming internal pressure.

The magnesium alloy material is introduced into the pipe forming to replace the original Low-carbon steel and stainless steel, and the weight of the pipe is reduced by about 75% [2], which satisfies the requirement of lightweight. The use of Magnesium alloy tubes are manufactured by internal high pressure of forming technology, and the use of grain force of magnesium alloy is changed by the use of hydraulic tension divergence, and many slip systems are set in motion, so the deformation resistance of magnesium alloy is reduced by 15-20% [3], which can form the special section and different wall thickness of pipe products at one time. The crystalline structure of magnesium is a dense row of six square crystal structures, and the symmetry is low. Its axle ratio (c/a) value is 1.623, closing to ideal dense row value 1.633. At room temperature, only the base plane {0001} produces the slip, and the slip coefficient is only 3 so the possibility which the crystal surface produces slippage is very limited, Therefore, the plasticity of magnesium alloy is low and the deformation in cold state is very difficult[4]. With the increase of forming temperature and the formation of twin with more additional slip surface, the yield strength and tensile strength of magnesium alloy are obviously reduced, which can improve the plastic deformation ability[5].

2. Experimental Study on Plastic Deformation of Magnesium Alloy

2.1. Tensile Experiment

In this paper, the extrusion pipe of the magnesium alloy AZ31B was selected as the object of study, and a tensile test was cut from the tube, and the tensile test was carried out at different temperatures. The dimensions of the specimen are shown in figure 1:

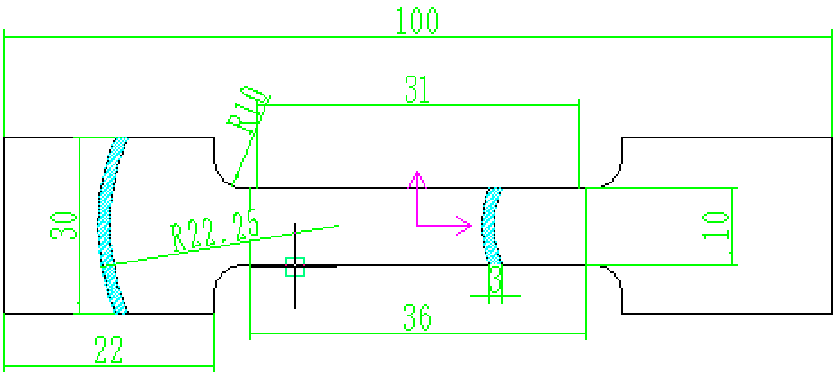

Figure 1. Tensile test sample

At 100 ℃, 150 ℃, 100 ℃, 250 ℃, 300 ℃, 350 ℃, six different temperatures warm tensile test. This stretch test stretch is 10^{-3}m/s. The stress strain curves of different temperatures were obtained by tensile test and then converted into real stress strain curves. By observing the real stress-strain curve can be found when the drawing speed is constant, the yield strength and tensile strength decreases with the increase of temperature, while total elongation increased with the rising of temperature. This is because as the temperature increases, with the formation of twin crystals, more additional slip surfaces are produced and the plasticity of the magnesium alloy is greatly improved.

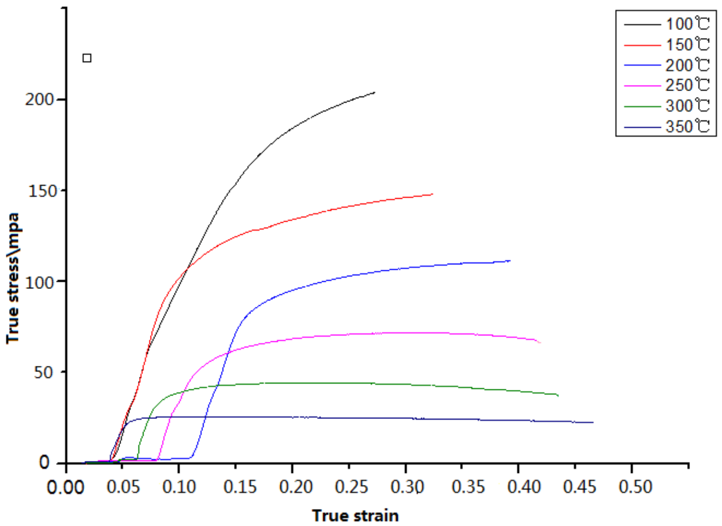

Figure 2. The real stress strain relation curves of AZ31B magnesium alloy pipes under different temperatures

2.2. Observe the Fracture with Sem

The fracture morphology of tensile specimens at six different temperatures was observed by sem scanning electron microscope.Figure 3 is the sem diagram at different temperatures.Can be seen from a to f, ductile nest did not appear at 100 ℃, at this point belongs to brittle fracture. Can be seen from a to f, ductile nest did not appear at 100 ℃, at this point belongs to brittle fracture. As the temperature rises, the ductile nest becomes more and more large, more and more, and the depth becomes larger and larger, indicating that the ductile fracture is at this time and the plasticity gradually becomes better. When the temperature reached 350 ℃, the magnesium alloy has good plasticity and shape ability. Considering the actual production of saving energy and reducing consumption, the mold after heat loss factors, choose 250 ℃ for magnesium alloy molding temperature, the temperature of forming ability to meet the actual production.

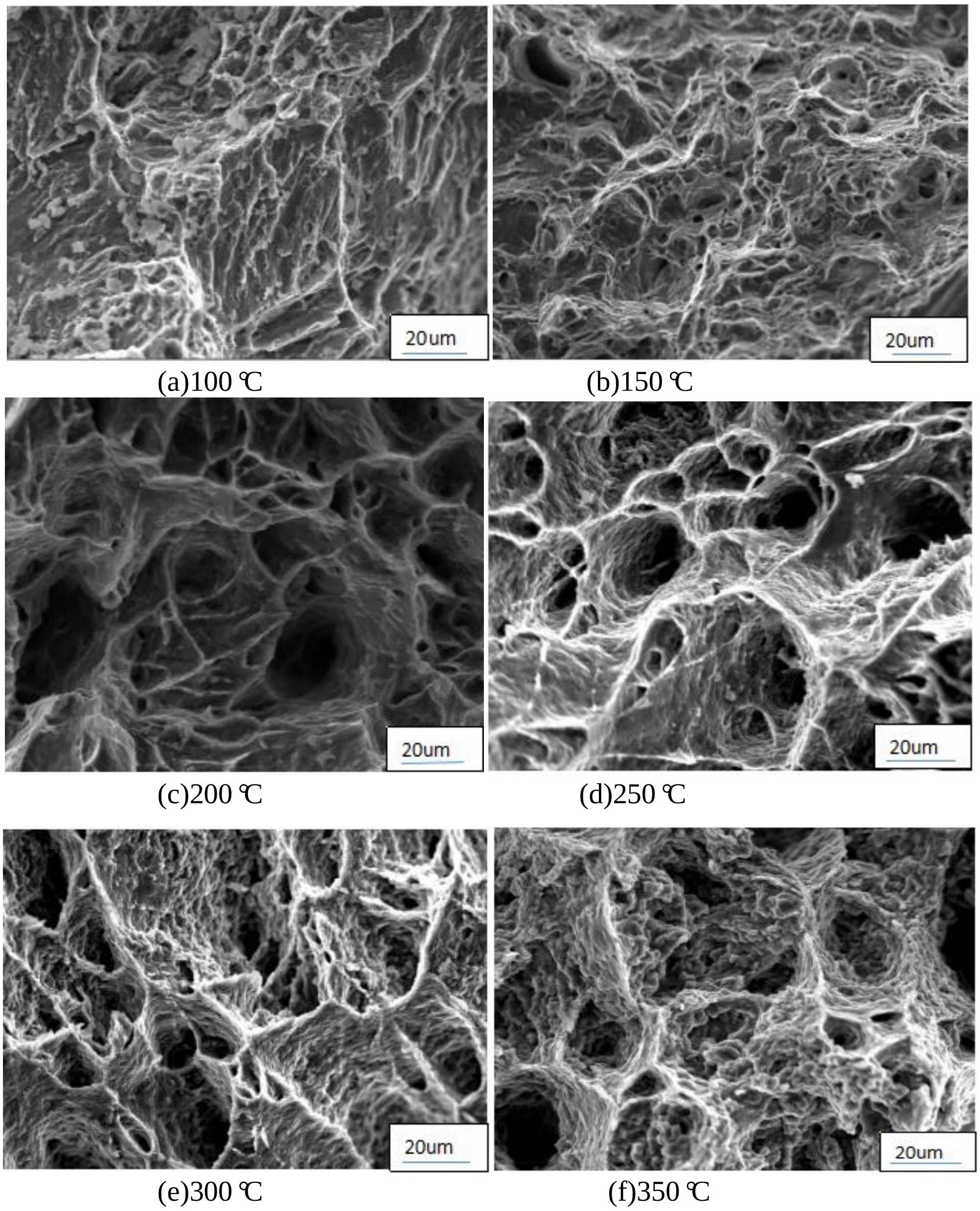

Figure 3. Above is broken at different temperatures

3. Finite Element Analysis of Magnesium Alloy Special-Shaped Tubes

Through the above experiments, the plasticity of magnesium alloy was improved with the increase of temperature. Considering the actual production of saving energy and reducing consumption, the mold after heat loss factors, select 250 ℃ as the magnesium alloy pipe forming temperature. This temperature is sufficient to meet the plasticity required for molding. Using the magnesium alloy performance parameters at this temperature, a finite element simulation and simulation of the internal high pressure forming of a special-shaped tube (Fig. 4) was carried out to observe the forming effect.

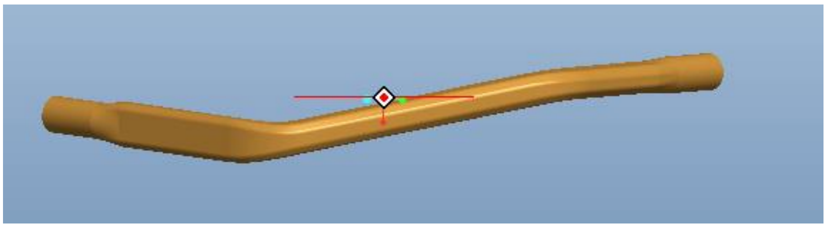

Figure 4. Shaped tube

3.1. Bending Simulation and Simulation of Pipe Fitting

Because the axis of the special-shaped pipe is in many planes, in the forming process, in order to put the tube blank into the mould, the tube blank is bent into the general shape of the special-shaped pipe. In the process of bending, due to the bending of the tube billet, the corner will appear thinning and thickening phenomenon, if the transition is thinning or transition thickening, will cause rupture and fold phenomenon. Therefore, it is necessary to control the forming parameters well, which is the premise to ensure the smooth development of the internal high pressure forming process. DYNAFORM software was used to simulate the tube bending, and the forming limit and wall thickness distribution were obtained.

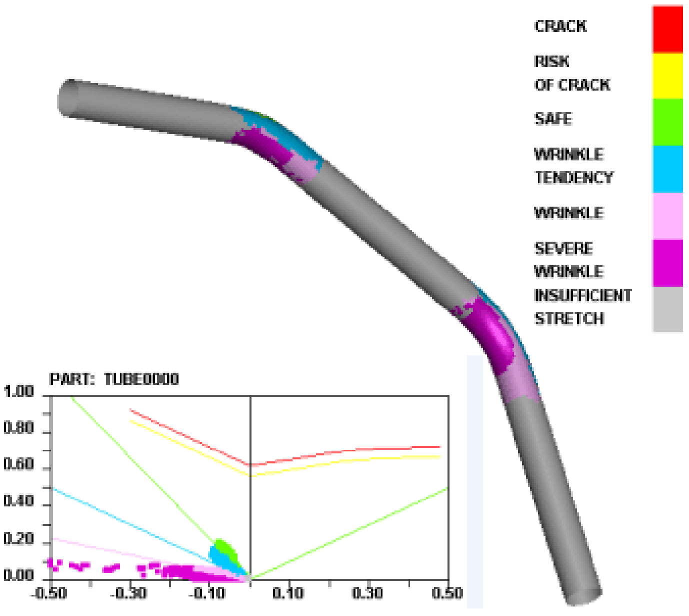

Figure 5. Forming limit of bent pipe

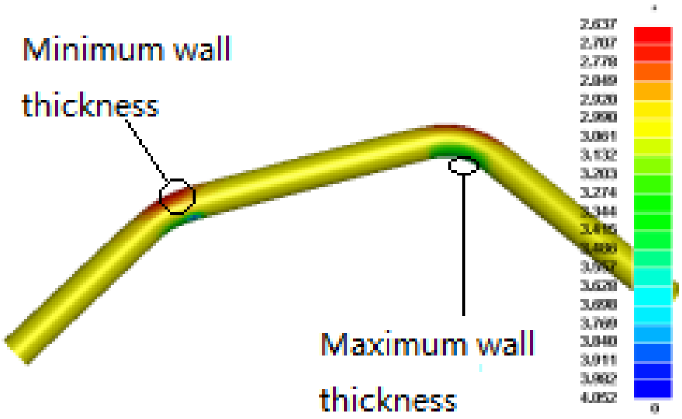

Figure 6. Wall thickness simulation of tube

From the forming limit diagram of Figure 5, it can be seen that at the corner of the bend, there is no exceeding the forming limit, and there is no defect of rupture and wrinkle. From the wall thickness distribution of Figure 6, it can be seen that the maximum wall thickness is 3.486mm, which appears in the corner concave, and thinner than the original tube blank. The minimum wall thickness is 2.637mm, which appears at the corner convex. Compared with the original tube blank, the wall thickness increases.

3.2. Preforming

When the tube bending process is finished, the minimum width of the end face structure of the opposite pipe is smaller than that of the original pipe blank, which will make the bent tube blank not put into the forming die normally. So it is necessary to add a forming process: preforming. This procedure has three purposes: the first is the tube diameter is greater than the minimum width of flat shaped tube preform, so as to facilitate the tube bending into the mold, to avoid flash phenomenon. The second is to evenly distribute the tube blank material in advance so as to avoid the forming fold and rupture caused by uneven material. The third is a reasonable preform shape, which can reduce the shaping pressure of the transition fillet, reduce the clamping force, improve the forming efficiency, and save the resources.

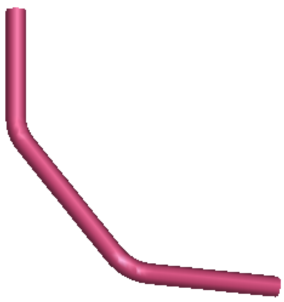

Figure 7. Bent tube billet

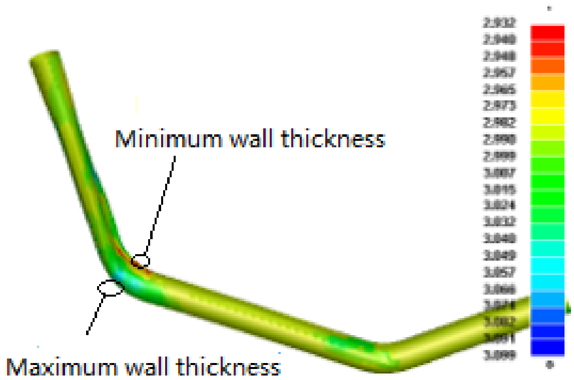

Figure 8. Wall thickness distribution of curved tube blank

Figure 7 is the original tube blank, because the tube blank diameter is larger than the minimum width of the special-shaped tube, so tube flattening is carried out ahead of time. Figure 8 is the tube wall thickness distribution after flattening, the maximum wall thickness is 3.066, the minimum wall thickness is 2.932, the wall thickness is uniform, no rupture and fold phenomenon.

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3.3. Internal High Pressure Forming [6]

First, the high-pressure liquid into the tube, in accordance with the set of forming the internal pressure loading curve pressure, under the action of high pressure, the tube blank paste, forming the required special-shaped tube.In order to ensure the quality of forming, before forming, the need to calculate the parameters of forming pressure.

3.3.1. Calculation of initial yield pressure p_1 .The minimum internal pressure required at the beginning of the plastic deformation of the tube is called the yield pressure, and its specific size is determined by the properties and geometries of the tube material.The initial yield pressure when no axial force is applied can be calculated using the formula (1).

$$p_1 = \frac{2t}{d}\delta_s \tag{1}$$

Where: δ_s is the yield strength of the tube material,*t* is the initial thickness of tube blank,*d* is the tube blank diameter.

*3.3.2. Calculation of limit pressure P_2.*So that the tube bulge to no break when the limit of the internal pressure can be calculated using the formula (2).

$$p_2 = \frac{2t}{d}\delta_b \tag{2}$$

Where: δ_b is the tensile strength of tube blank, *d* is the tube blank diameter.

*3.3.3.Calculation of shaping pressure P_3.*In the final stage of internal high pressure forming, the basic shape of the special-shaped tube has been formed. In order to ensure the forming accuracy of the transition fillet of the section, more internal pressure is needed.This stage is known as plastic pipe forming, the forming pressure eventually forming pressure.The final molding pressure can be calculated using the formula (3).

$$p_3 = \frac{t}{r_c}\delta_s \tag{3}$$

Where:*t* is the Average thickness at transition fillet,*rc* is the minimum transition fillet radius of workpiece cross section.

*3.3.4.Final forming simulation.*The forming simulation and Simulation of the final forming were carried out by forming simulation in DYNAFORM software, and the forming limit and wall thickness distribution map were obtained.The internal pressure of the final forming is 35MPa by calculation.Because there is no special complex structure in the pipe, there is no need to provide axial feed.

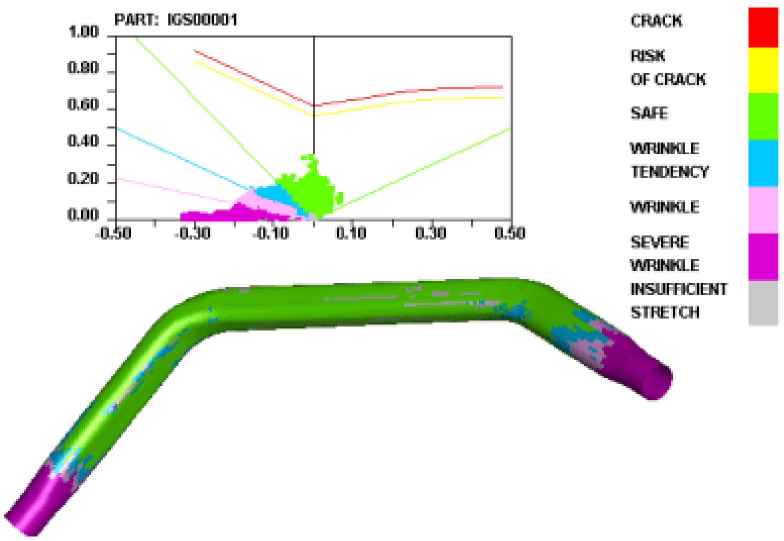

Figure 9. Forming limit diagram

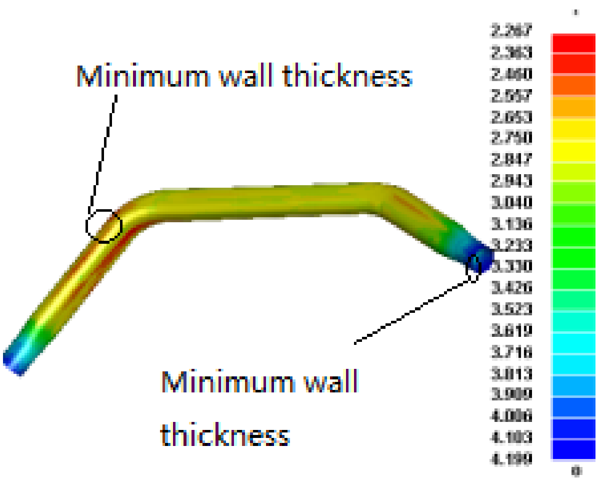

Figure10 . Wall thickness distribution

It can be seen from figure 9 and figure 10 that the shape of the tube is within the forming limit, and there is no rupture phenomenon. The minimum wall thickness is 2.267mm, and the maximum wall thickness is 4.199mm. No wrinkling, rupture and other defects, forming the ideal result.

4. Conclusion

Through the above experiments, it can be concluded that with the increase of temperature, the plastic forming ability of magnesium alloy AZ31B is getting better and better. Taking into account the actual production of energy saving, loss of heat after the mold and other factors, choose 250 degrees of magnesium alloy molding temperature, the molding ability at this temperature to meet the actual production. The material performance parameters at this temperature are applied to the finite element analysis of profiled tube forming. By observing the wall thickness distribution and forming limit diagram of special-shaped tubes, the forming effect is good. The above results verify the feasibility of warm internal high pressure forming of magnesium alloy tube, and will have a good prospect in the future.

5. Acknowledgements
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