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Viscous warm pressure bulging process of AZ31B magnesium alloy with different ellipticity dies

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Abstract: Based on the bulging principle of different ellipticity dies, the methyl vinyl silicone rubber with excellent thermal stability and heat transfer performance was chosen as the viscous medium. The finite element analysis and experiments of viscous warm pressure bulging (VWPB) of AZ31B magnesium alloy were conducted to analyze the influence of different ellipticity dies on the formability of AZ31B magnesium alloy. At the same time, based on the grid strain rule, the forming limit diagram (FLD) of VWPB of AZ31B magnesium alloy was obtained through measuring the strain of bulging specimens. The results showed that at the temperature range of viscous medium thermal stability, the viscous medium can fit the geometry variation of sheet and generate non-uniform pressure field, and as the die ellipticity increases, the difference value of non-uniform pressure reduces. Meanwhile, according to the FLD, the relationship between part complexity and ultimate deformation was investigated.
Key words: AZ31B magnesium alloy; viscous warm pressure bulging; formability; different ellipticity dies; forming limit diagram

1 Introduction

With the improvement of energy saving requirements and lightweight technology, the magnesium alloys are widely applied in aviation and other transportation fields owing to a desirable combination of characteristics such as high specific strength, low density and easy recovery [1−3]. Unfortunately, the plasticity of magnesium alloys is generally lower compared with steel and aluminum alloy at room temperature due to the hexagonal crystal packed crystal structure, so the applications of magnesium alloys are limited in industrial field. The formability of magnesium alloy can still be improved significantly in certain high temperature [4−8]. Therefore, the warm forming process has become an important way to realize the forming of magnesium alloy sheet metal with complex shape. ZHENG et al [9] performed the warm hydroforming process of magnesium alloy, the liquid pressure and loading speed were optimized at warm condition. The forming of magnesium alloy parts with complex shape which could not be realized at room temperature was realized through warm hydroforming process. The warm deep drawing experiment of AZ31 magnesium alloy square part was carried out by CHANG et al [10]. Different variation schemes of blank holder force were tested. The best scheme was that with the increasing of punch stroke, the blank holder force increased firstly and then decreased. Through adopting the best blank holder force scheme, the deep drawing depth of AZ31 magnesium alloy square part can be improved greatly. MENG et al [11] tested the limit strain of AZ31 magnesium alloy sheet at 25−230 °C through combining electromagnetic forming and warm forming. In this way, the limit strain of AZ31 magnesium alloy sheet was enhanced with the increasing of temperature. In the study by AMBROGIO et al [12], the warm incremental forming of AZ31 magnesium alloy was conducted and the process parameters were optimized through finite element analysis and experiments. The formability of AZ31 magnesium alloy was improved significantly by warm incremental forming process.

A kind of semisolid, flowable and high viscosity polymer with excellent thermal stability and heat transfer performance and certain rate sensitivity was chosen as pressure-carrying medium during viscous warm pressure bulging (VWPB) process. Compared with traditional

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warm forming methods, viscous medium could fit the geometry variation of sheet and generate the required high pressure. The large adhesive force between sheet and viscous medium could change the strain−stress state and control the flow rule of sheet during the forming process. A non-uniform pressure field could be generated to improve the formability of specimens due to the strong strain rate sensitivity of viscous medium [13−17]. In this work, the methyl vinyl silicone rubber with excellent thermal stability and mechanical property was chosen as viscous medium during warm forming process. On this basis, the research on VWPB process of AZ31B magnesium alloy with different ellipticity dies was conducted. Then, the influence of part complexity on the deformation rule and characteristic of AZ31B magnesium alloy VWPB were observed. At the same time, the FLD of viscous warm forming of AZ31B magnesium alloy was obtained, which provided an important reference for the application of viscous warm forming technology of magnesium alloys [18−21].

2 Experimental

2.1 Experimental principle and scheme

The principle of viscous warm pressure bulging is illustrated in Fig. 1. The die, sheet, viscous medium and container were heated to setting temperature using the heater and then the temperature was maintained for 30 min to ensure the temperature stable. Finally, the piston moved upward to push the viscous medium, which caused the deformation of magnesium alloy sheet. In the experiments, the long axis lengths of ellipticity dies (L) were all 60 mm and the short axis lengths of ellipticity dies (D) were 36, 42, 48, 54 and 60 mm, respectively and then corresponding ellipticities λ ($\lambda=D/L$) were 0.6, 0.7, 0.8, 0.9 and 1.0, respectively.

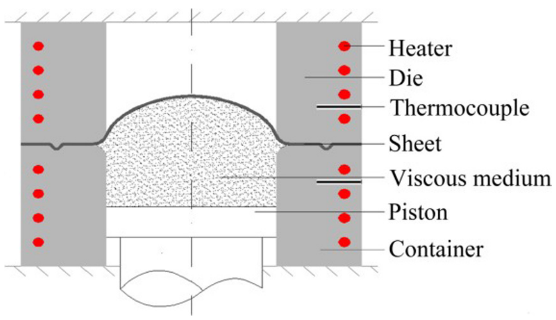

Fig. 1 VWPB principle

2.2 Property of viscous medium

Methyl vinyl silicone rubber is a kind of colorless and visco-plastic polymer which is copolymerized with dimethyl siloxane and little vinyl silicone. The methyl vinyl silicone rubber with 600000 g/mol molecular mass was chosen as viscous medium during experiments. The molecular structural formula of methyl vinyl silicone rubber is illustrated in Fig. 2. The flow and compression properties of methyl vinyl silicone rubber at different temperatures are illustrated in Fig. 3. Its bulk modulus reduced and the fluidity increased incessantly with the temperature. As the temperature exceeded 250 °C, the methyl vinyl silicone rubber decomposed into cyclic siloxane oligomer and other small molecule, then it was aged and lost elasticity.

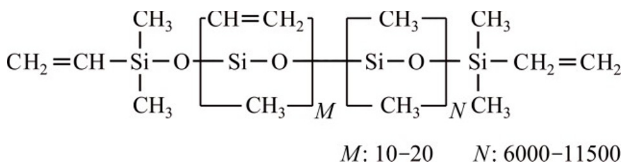

Fig. 2 Molecular structural formula of methyl vinyl silicone rubber

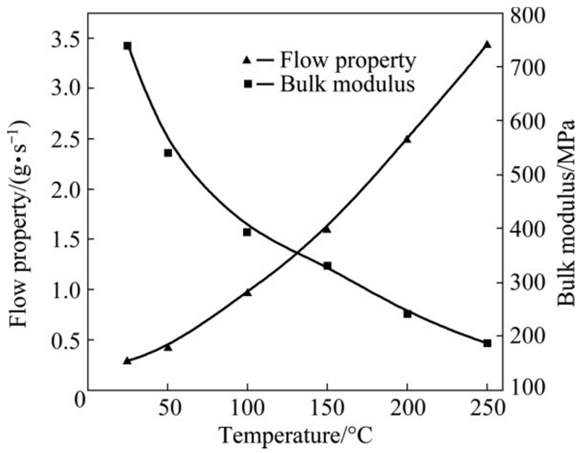

Fig. 3 Flow and compression properties of methyl vinyl silicone rubber at different temperatures

2.3 Property of AZ31B magnesium alloy

The AZ31B magnesium alloy with a thickness of 0.8 mm was annealed to relief the residual stress. Considering the thermal stability temperature range of viscous medium, the limit bulging experiments of AZ31B magnesium alloy with the speed of 0.2 mm/s were conducted at temperatures of 20, 100, 150, 200 and 250 °C in turn. The results of limit bulging experiments are shown in Fig. 4.

As the temperature increased, the limit bulging height of magnesium alloy increased, and reached the maximum at 200 °C, but it decreased at 250 °C. It was because the molecular chain of viscous medium was in active state and properties changed a lot at 250 °C, which affected the formability of magnesium alloy.

3 Finite element analysis

3.1 Finite element analysis model

In order to study the deformation rule of both