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Stamping Formability of ZE10 Magnesium Alloy Sheets

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Abstract: ZE10 magnesium alloy sheets were prepared through ingot casting and the hot-rolling process. The mechanical properties, conical cup value (*CCV*), bore expanding performance, and limit drawing ratio (*LDR*) were investigated to examine the stamping formability of ZE10 alloy sheets, at temperatures ranging from 20 to 300 ℃. The results showed that the tensile strength decreased, whereas, plasticity, drawing-bulging performance, bore expanding properties, and deep drawing performance increased markedly at elevated temperatures. The CCV specimens could be drawn into the conical die's underside cylindrical hole from the conical cliff, without cracking, and could have the minimum *CCV* at 200 and 250 ℃. In the bore-expanding test, the bore (Φ10 mm) could be expanded to the dimension of the punch (Φ25 mm) and the maximum bore-expanding ratio could be achieved at above 150 ℃. The limiting drawing ratio (*LDR*) of 2.85 is acquired during the deep drawing test at 230 ℃ with the punch temperature of 20 ~ 50 ℃, the punch velocity of 50 mm · min^{-1}, and the mixture of graphite and cylinder grease as lubricant.

Key words: ZE10 magnesium alloy; conical cup value; bore expanding performance; limit drawing ratio; rare earths
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On account of its lightweight and high specific strength, the magnesium alloy has been widely used for structural components in aerospace, electronics, and the automobile industry, to replace some existing materials[1,2]. Nowadays, the principal manufacturing process has been die casting, and the formed products of magnesium have been limited, because magnesium is a hexagonal, close-packed metal and shows poor formability at room temperature. However, the casting process is not ideal for making thin-walled magnesium structures because of the excessive amount of waste material. A potential solution would be to resort to the press forming process of sheets, so that the fabrication processes of press forming and stamping of magnesium-alloy sheets become especially important. The magnesium alloy's formability can be considerably increased in the temperature range from 200 to 225 ℃ (depending on the alloy composition), because of the thermal activation of the pyramid sliding planes in the hexagonal structure[3]. The magnesium alloy can be effectively processed by increasing the working temperature to above 200 ~ 300 ℃. Deep drawing tests with magnesium alloys AZ31B, AZ61B, and M1 at a temperature range between 200 and 250 ℃ investigated by Doege[4], indicating that magnesium alloys show very good formability. The AZ31B sheet realized its limit, drawing ratios up to *LDR* = 2.52, and AZ61B and M1 showed maximum values of approximately *LDR* = 2.20 ~ 2.25 at 200 ℃. Rare earth (RE) elements are useful in refining the microstructure

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of the magnesium alloys and in improving the mechanical properties, and have high temperature performance and corrosion resistance[5 ~ 7]. ZE10 alloy is an Mg-Zn-Zr alloy with a few rare earth elements (RE), and ZE10 sheets have medium strength and good plasticity[8]. In the present study, the stamping formability of magnesium-alloy ZE10 sheets was investigated using experimental approaches including mechanical properties, conical cup value (*CCV*), bore expanding performance, and limit drawing ratio (*LDR*) at elevated temperature.

1 Experimental

The material used in the present investigation was a Mg-1.0% Zn-0.3% RE-0.3% Zr alloy sheet (mass fraction). The alloy was prepared by adding the following alloying materials: commercial pure Mg (99.9% Mg), Zn, Mg-20% Zr master alloy, and cerium-rare earth (RE, mainly composed of 50.4% Ce and 40.7% La). The alloy was held in the resistance furnace in a mild steel crucible and protected by CO_2 and SF_6 mixed gases. The melt was held at 780 ℃ for 30 min to make the RE metal dissolve completely, and then it was refined and cooled down to the pouring temperature of 700 ℃ and cast into a permanent mold. After it was homogenized at (410 ± 5) ℃ for 8 h, the ingot was warm rolled at 300 ~ 420 ℃ to a thickness of 1.0 mm with an average reduction ratio of 20% and a total reduction ratio of 95%.

All tensile tests were carried out on SANS CMT5105 testing machine. The mechanical properties of ZE10 alloy sheets were examined at temperatures ranging from 20 to 300 ℃. The gauge length and the width of specimens were 25 and 10 mm, respectively.

The *CCV* tests were performed on the universal testing machine according to the GB/T 15825.6-1995 standard. Fig. 1 shows the schematic diagram of the *CCV* test and the dimensions of die and punch. The circular specimen had a diameter of 50 mm and a thickness of 0.95 mm. When the test was conducted, a circular sheet blank was placed on the top of the die, which had a conical cavity and an underside cylindrical hole at the center. Then the punch with the spherical head moved down with a velocity of 2.5 mm · min^{-1} to deform the sheet blank until it got fractured. The measured critical diameter of the fractured conical cup was defined as the *CCV*. For the circular blank with a specified diameter, a smaller value of *CCV* implied a larger drawing depth, resulting in better formability. There was no blank-holder used in the *CCV* test, so the effect of the blank-holder force could be excluded in the test.

The schematic diagram of the tools for the bore expanding tests is shown in Fig. 2. Square specimens with an initial machined bore in the center were prepared. The side length was about 60 mm and the diameter of the bore was (10 ± 0.05) mm. The blank holder force was kept constant at 2 kN and the punch velocity was 2.5 mm · min^{-1} during the test. The bore-expanding ratio λ was evaluated as

$$\lambda = \frac{d_f - d_0}{d_0} \times 100\% \tag{1}$$

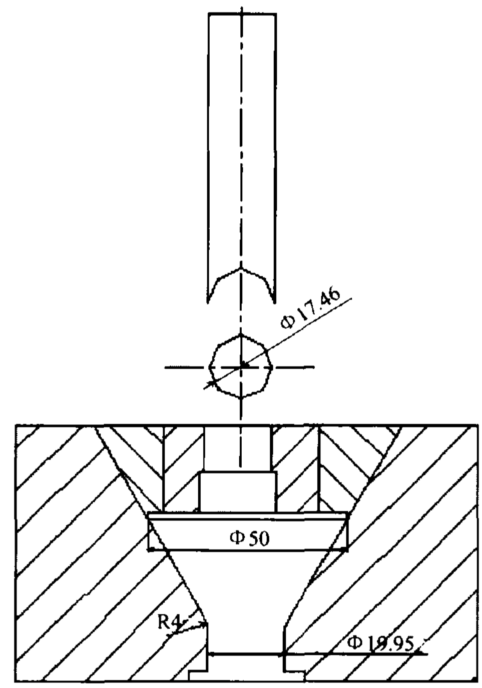

Fig. 1 Schematic diagram of *CCV* test (mm)

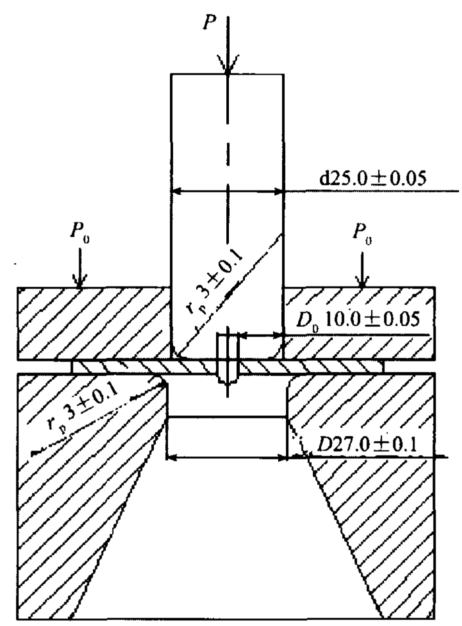

Fig. 2 Schematic diagram of bore expanding test (mm)