Experimental Investigation on Pulsed Current Influence on U-bending of AZ31B Magnesium Alloy

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Abstract. The electropulse effect (EPE) is combined with the bending forming of magnesium alloy sheet. Through electropulse assisted (EPA) magnesium alloy U-bending test, the influence of current parameters on the U-bending properties of magnesium alloy sheet was studied. Through the analysis of the microstructure of magnesium alloy sheet, the mechanism of EPE on the bending forming performance of magnesium alloy sheet was explored. It was found that the pulse current promotes the occurrence of dynamic recrystallization of the magnesium alloy, improves the forming ability of the magnesium alloy sheet, and reduces the springback angle of the magnesium alloy sheet bending.

1. Introduction

Magnesium and magnesium alloys are known as “green material” in the 21st Century for their excellent mechanical properties. Magnesium and magnesium alloys are widely used in aerospace, automotive, electronics, communications, and other fields due to their good performance [1]. However, due to the hexagonal crystal structure of magnesium alloys, magnesium alloys have poor plastic forming ability at room temperature, which limits the application of magnesium alloys in the industrial field and has become a major factor restricting the development of magnesium alloys in the industry [2].

Guoyi Tang et al. [3-5] studied the electropulse drawing and rolling of magnesium alloys found that pulsed current can promote the movement and climbing of movable dislocations, open the dislocation tangles, change the dislocation density, reduce the flow stress of the material, and find that the pulse current can promote dynamic recrystallization of magnesium alloys at lower temperatures. Perkin [6] studied the forming properties of aluminum alloys and other metals through electropulsing upsetting experiments, and found that the electropulsing significantly improved the plastic forming ability of aluminum alloys. The deformation before fracture was significantly improved, and the deformation resistance decreased significantly. Bao et al. [7] studied the electropulsing assisted(EPA)magnesium alloy incremental forming experiments found that the parameters of the electropulse have a significant influence on the progressive forming limit of the sheet. With the increase of the pulse current, the forming limit is significantly improved, and the forming ability is significantly enhanced. It proved the existence of pure EPE. Conrad [8] proposed that the pulsed current can increase the internal energy of the material and thus promote the thermal

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activation process of the dislocation movement. Molotskii [9] explains the mechanism of pure electroplastic effect through induced magnetic field theory.

In this paper, the EPE is combined with the bending forming of magnesium alloy sheet, based on a self-designed experimental mold. Through EPA magnesium alloy bending forming test, the influence of current parameters on the U-bending properties of magnesium alloy sheet was studied. Through the analysis of the microstructure of magnesium alloy sheet, the mechanism of EPE on the bending forming performance of magnesium alloy sheet was explored.

2. Test equipment and materials

The test specimen is AZ31B magnesium alloy, dimensions 90mm x 20mm x 1.2mm, the test device was shown in Figure 1. In order to prevent the test piece and the concave-convex die from being incompletely contacted, when the punch reaches 1mm, the device which is shown in the Figure 1 starts to energize until the end of the test. To study the influence of pulse current on the U-bending forming, the adopted punch fillet radius is set to 4mm, die clearance is set to 1.1t, t is the thickness of the sheet, the impulse current generator and electropulsing waveform Figure 2, the forming rate is 15mm/min. In order to ensure the accuracy of the test results, each set of tests was performed three times. The angles of the two right-angled sides of the formed test piece were measured by a universal protractor. The average value of the three test results was taken as the forming angle value. After the test was completed, the microscopic metallographic test was performed by an Axio Lab A1 optical microscope.

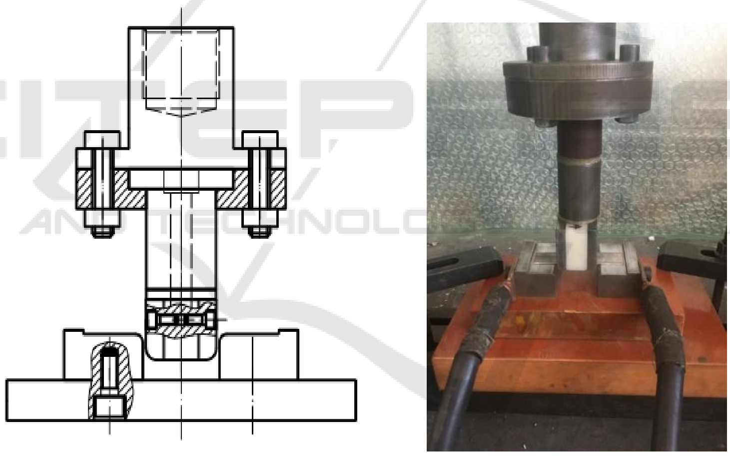


Figure 1. U-bending die setup schematic diagram and setup device.

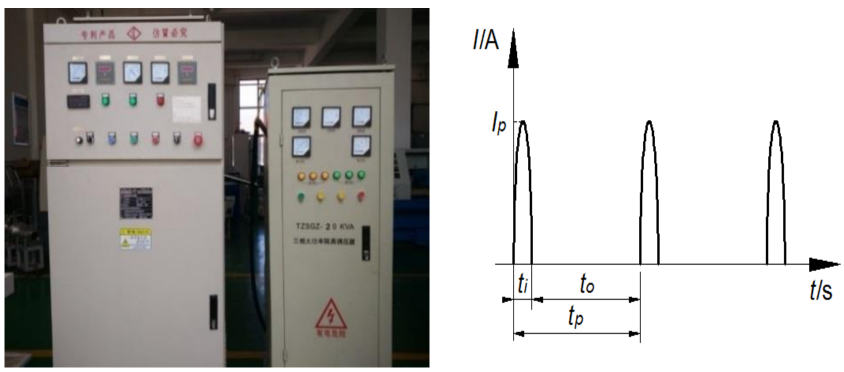


Figure 2. Impulse current generator and pulse current schematic diagram.

3. Experimentation results and discussion

3.1. Experimentation results

The forming angle of the magnesium alloy test without current is taken as a reference. The forming angles of U-bending tests under different pulse current were shown in Table 1. The formed specimens were presented in Figure 3.

Table 1. The results of EPA U-bending.

Sample	Voltage(V)	Frequency(Hz)	Forming angle(°)
0	-	-	114.5
1	50	200	112.3
2	70	200	110
3	70	350	108.5
4	80	350	107
5	70	450	106.2
6	90	350	103.3

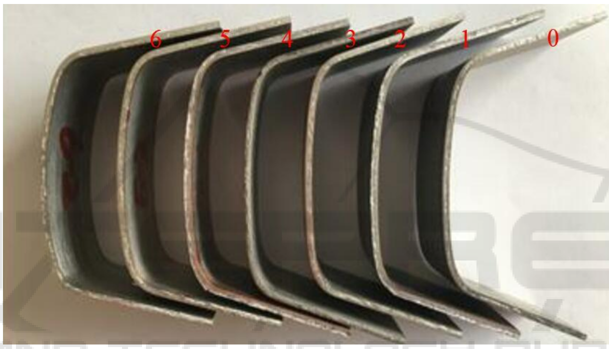


Figure 3. The specimens of EPA U-bending.

With reference to Figure 3. and Table 1., it can be found that with the increase of the pulse current parameters, the forming angle of the U-shaped bending part of the magnesium alloy gradually decreases. That is, with the increase of the pulse current parameter, the springback angle of the U-shaped bending of the magnesium alloy gradually decreases. The U-shaped bending angle curve of the EPA magnesium alloy under different pulsed electric parameters was shown in Figure 4.

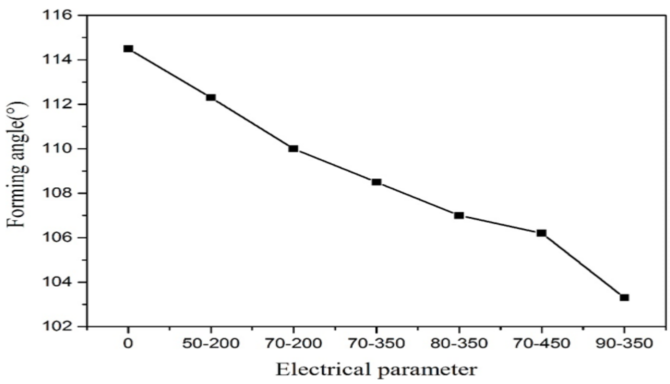
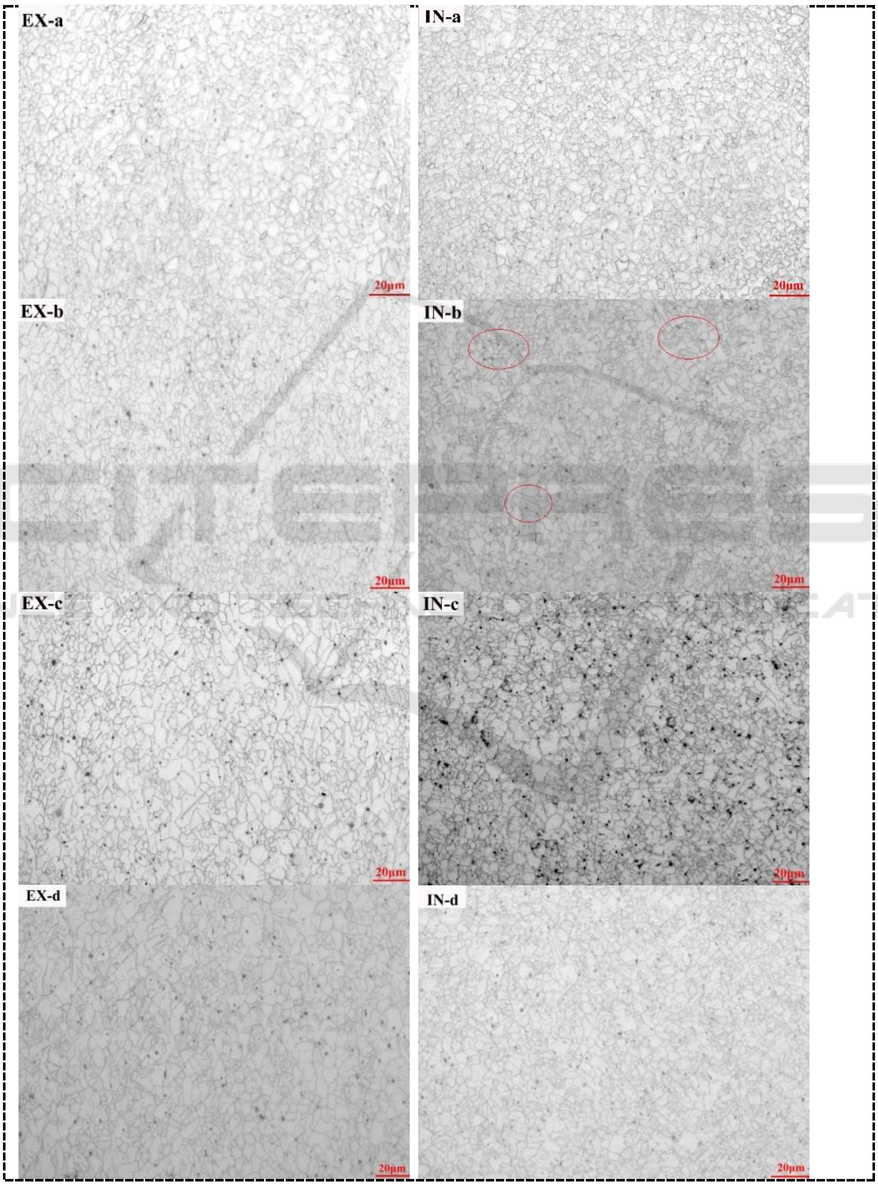


Figure 4. Forming angle curves under different electric parameters.

Figure 4 shows that with the increase of electrical parameters, the forming angle gradually decreases, and in the selected range of electrical parameters, the U-shaped bending angle of the magnesium alloy basically shows a linear decrease trend.

3.2. Investigations on microstructure

For U-bending process, before the calibration stage, for the main deformation region of the test piece, the interior region of fillet radius is under compression stress state and the exterior region of fillet radius is under tension stress state. The microstructure of the main deformation zone (fillet radius) of the U-bending specimen was obtained as shown in Figure 5.



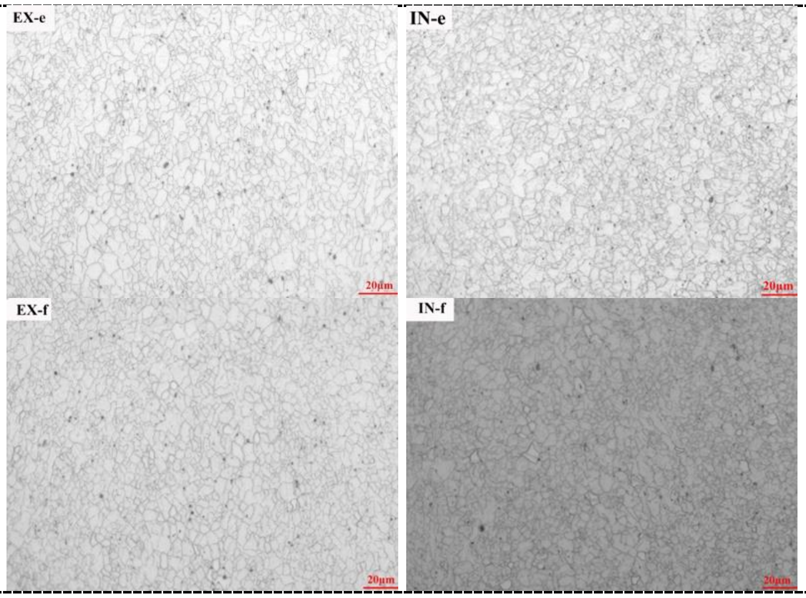


Figure 5. The microstructure of specimens under EPA U-bending (EX represents the extrados of the specimen, IN represents the intrados of the specimen. (a) (b) (c) (d) (f) are No current, 50V-200Hz, 70V-200Hz, 70V-350Hz, 70V-450Hz, 90V-350Hz).

Figure 5 (a) and (b) show the microstructures of the external and internal fillet radius zone at room temperature. Figure 5 (a) presents that the large grains are stretched and twinning occurs in some coarser grains. Slip is the main deformation mechanism for the external zone. In Figure 5 (b), many twins that marked with ellipses can be observed, even in some small grains. Twin is the main deformation for the internal zone. The difference between the internal and external deformation mechanisms determines the microstructures. Figure 5 (c) and (d) show when the pulse current parameter is small, the microstructure of curved specimens has not changed much compared to the U-bending at room temperature. Figure 5 (c) and (d) have similar microstructures. A large number of twin grains occur in the interior. It is meant that twinning is the main deformation for the internal zone, and slip is the main deformation mechanism for the external zone. With the increase of the electrical parameters until 70V-350Hz, the microstructure does not change significantly, meaning that EPE is not significant. The fine grains are generated at the grain boundaries of some coarse grains at the internal fillet radius zone above 70V-350Hz. It is indicated that the dynamic recrystallization of Magnesium alloy begins to occur under pulsed current. Conrad et al. [10] found that pulse current has "thermal effect" and "althermal effect". In this paper, their common actions are considered. The general deformation mechanism of a material having the same HCP structure as that of magnesium are twinning and dynamic recrystallization. The process of dynamic recrystallization is opposite to static recrystallization, the nucleation and growth of new grains occur during deformation rather than later as part of a separate heat treatment [11]. The fine crystallites produced by dynamic recrystallization play an important role in coordinating the plastic deformation, contributing to improve the plastic forming ability and reduce the springback angle of the U-shaped specimen. As the electrical parameter increases to 70V-450Hz, the dynamic recrystallization begins to occur at the outside fillet radius zone of the U-bending specimen. A large number of fine equiaxed grains are observed in the interior region. The dynamic recrystallization occurs both at the inside and outside zones of the U-shaped specimen. The plastic forming ability of the magnesium alloy can be further improved, and the springback was reduced.

4. Conclusions

The pulse current can promote the occurrence of dynamic recrystallization of the magnesium alloy, improves the forming ability of the magnesium alloy sheet, and reduces the springback of the magnesium alloy sheet bending.

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