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Pulse current assisted drawability of AZ31B magnesium alloy sheets

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Abstract. The thermal effect and athermal effect such as electro-plastic effect of metallic materials induced by high density current can dramatically reduce the flow stress, which is beneficial to the forming process of less formable metal. In this paper, pulse current-assisted deep drawing of the magnesium alloy is proposed due to lower energy consumption and higher efficiency. In this process, the metal sheet is designed in series in a pulse current circuit and heated directly by the pulse current. In addition, the insulated mould is employed to avoid the current leaking. Experiments were conducted to demonstrate the feasibility and advantages of the proposed process. An experimental process system was established and the electrical-assisted Erichsen cupping tests and rectangular cup drawing tests were performed. The experiments showed that the forming load was reduced and the cupping height and associated principal strains were increased in the Erichsen cupping and deep drawing process assisted by high-density electric current.

1. Introduction

Recent efforts in the automotive industry to improve fuel efficiency are reflected in the increasing use of lightweight materials. Magnesium alloys have been investigated to verify their high potential for use as light weight structural components in auto-motive applications, which results from their excellent properties, such as a low density and a high specific strength. However, the poor formability of magnesium alloy sheets, especially at room temperature, is one of the main factors hindering their industrial application [1-3]. In the traditional industry, warm or hot forming was commonly employed to manufacture the magnesium parts with a desired shape, because elevated temperature decrease the flow stress and increase the ductility of magnesium alloys. The traditional thermal forming method of heating the sheets via a furnace has many disadvantages, such as the decrease in the temperature of the sheets removed from the furnace prior to forming [4-5]. The sheets usually need to be heated to a higher temperature because of the heat dissipation. In addition, the sheets exposed to the air suffer a significant amount of oxidation due to the longer heating time. Therefore, reducing the process time and improving heat rates remain the major challenges.

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As a developing technique, pulse current auxiliary forming technique has arrested the attention of researches for high heating rate and electro-plastic effect. The thermal effect and athermal effect such as electro-plastic effect of metallic materials induced by high density current can dramatically reduce the flow stress, which is beneficial to the forming process of less formable metal [6-10]. In this paper, pulse current-assisted deep drawing of the magnesium alloy is proposed due to lower energy consumption and higher efficiency. In this process, the metal sheet is designed in series in a pulse current circuit and heated directly by the pulse current. In addition, the insulated mold is employed to avoid the current leaking. Experiments were conducted to demonstrate the feasibility and advantages of the proposed process. An experimental process system was established and the electrical-assisted Erichsen cupping tests and rectangular cup drawing tests were performed.

2. Experimental procedure

2.1 Experimental materials
A commercial AZ31B Mg alloy sheet was provided by POSCO using a strip casting process. The thickness of the sheet was 1.4 mm. The chemical composition of the AZ31B Mg alloy sheet is listed in Table 1. The microstructure of the as-received material is shown in Fig. 1, which shows equi-axed grains with an average size of 10 μm. A strong basal texture, which is a typical rolling texture of magnesium alloys, produced extension twin boundary in the grains. Engineering stress–strain curves at various are also represented in Fig. 2.

Table 1. Chemical composition of the AZ31B Mg alloy sheet (wt%)

Al	Mn	Zn	Ni	Fe	Mg
2.5-3.5	0.2-1.0	0.6-1.4	<0.005	<0.005	Bal.

Figure 1. Optical microscopy of the as-received AZ31B sheet

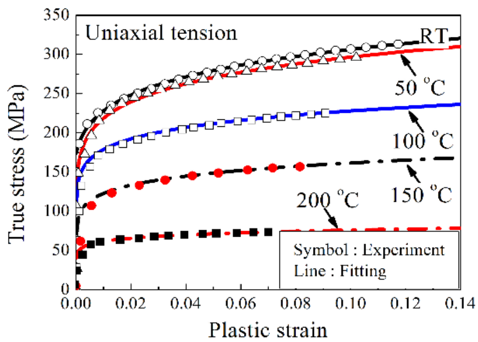
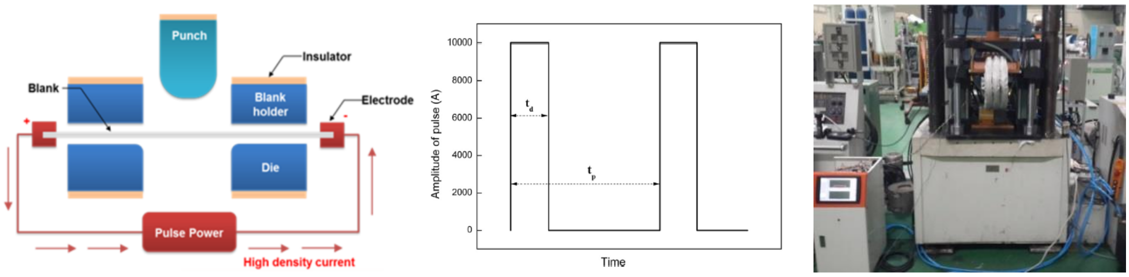


Figure 2. Engineering stress–strain curves of AZ31B at various temperatures

2.2 Experimental apparatus
Pulse current assisted forming apparatus was shown in Fig. 3. The rectangular sheet was directly set into the dies. The two edges of the sheet were held between two electrodes, and enough pressure was applied to guarantee sufficient contact for the electrifying. A laboratory-made electropulsing generator was used to acquire a maximum electro-pulsing of 10,000 A. The pulse current source was applied to discharge positive direction pulse with various parameters, including pulse width, frequency and amplitude. A typical wave form used in experiments is shown in Fig. 3(b), where t_d represents the pulse width, t_p is the pulse period. Hydraulic universal testing machine (UTM) was used for conducting the Erichsen and rectangular cup drawing tests with periodically pulsed currents. In order to prevent current leaking, electrical insulated bakelite were used to insulate every screw in the electrode and in the hydraulic testing machines.



(a) (b) (c)

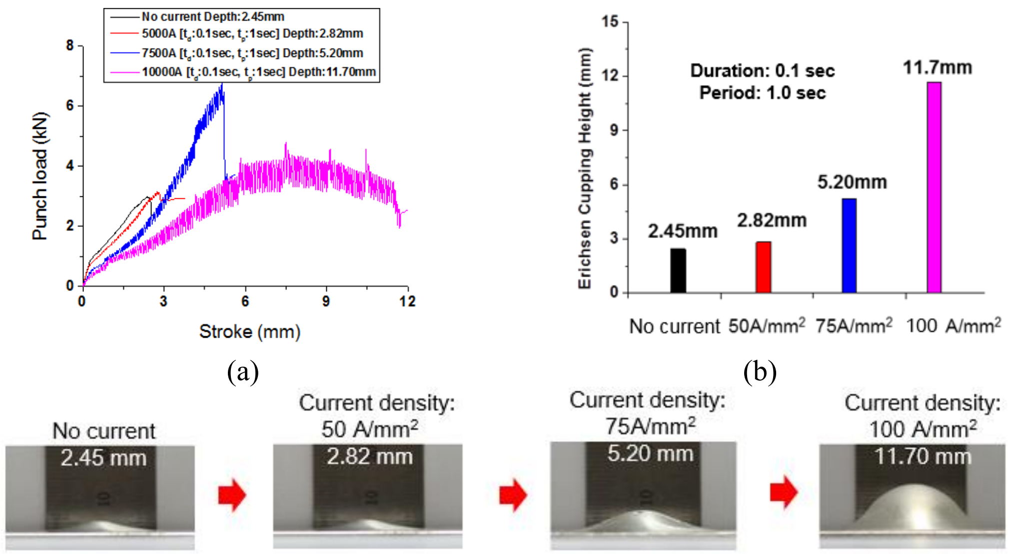
Figure 3. Apparatus of pulse current assisted forming (a) schematic diagram; (b) pulse current waveform; (c) device photo

3. Results

3.1 Pulse current assisted Erichsen tests

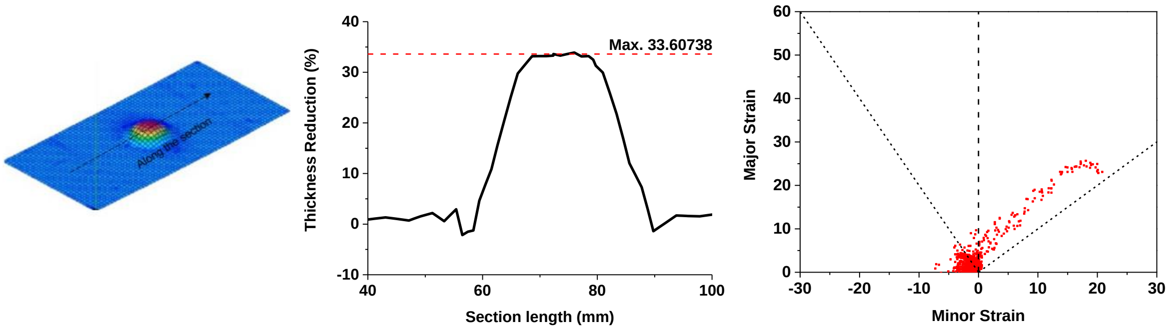
Pulse current assisted Erichsen tests for AZ31B were conducted with various pulsing conditions. For the quasi-static Erichsen tests under a pulsed electric current, the specimen was firstly set into the dies at room temperature and periodically pulsed with a constant amplitude of electric current over a selected duration while the specimen was continuously deformed by the movement of punch. In order to investigate the effect of the electrical pulsing on AZ31B, current density was changed from 50.0 A/mm^2 to 100.0 A/mm^2 while the pulsing duration and period were held constant value of 0.1 sec and 1.0 sec, respectively.

Fig. 4(a) represents typical load–displacement curves during conventional and pulse current assisted Erichsen tests. The punch load decreased instantly once a pulsed electric current was applied. After removing the pulsed electric current, the load increased with a transient behavior. The magnitude of load reduction increased because the electric current density increased as the cross-sectional area decreased.



(c)

Figure 4. Pulse current assisted Erichsen tests for AZ31B with various electric current densities; (a) punch loads and displacement curves; (b) Erichsen cupping heights; (c) deformed shape of samples.



(a) (b)

Figure 5. Erichsen tests with current densities of 100 A/mm^2: (a) thickness reduction; (b) major and minor strain distributions.

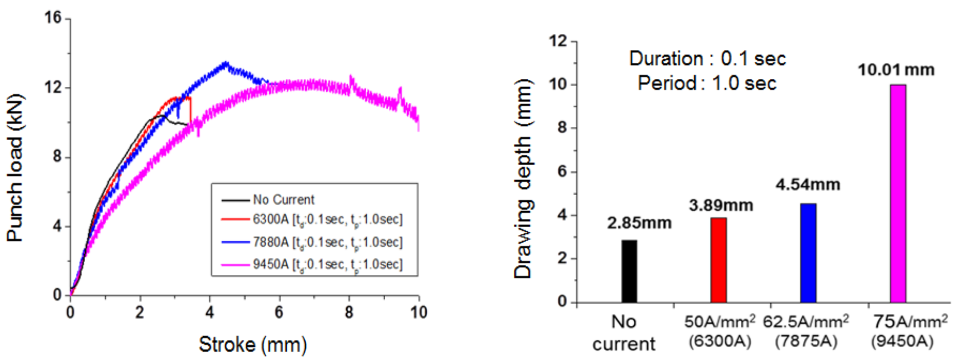
Fig. 4(c) illustrates the samples of AZ31 Mg alloy produced by tradition Erichsen tests and pulse current assisted tests at applying pulse current density of 50, 75 and 100 A/mm^2, respectively.

It is found that the Erichsen index (EI) increases when the electric current density increases while the other parameters keep the same. The maximum EI of 11.7 is obtained when the current density increases up to 100 A/mm^2. Thickness reduction and principal strains are also analysed as depicted in Fig. 5. The results indicate that AZ31B samples are bi-axially stretched with the maximum principal stain of 30 % without failure under electric pulsing conditions.

3.2 Pulse current assisted deep drawing tests

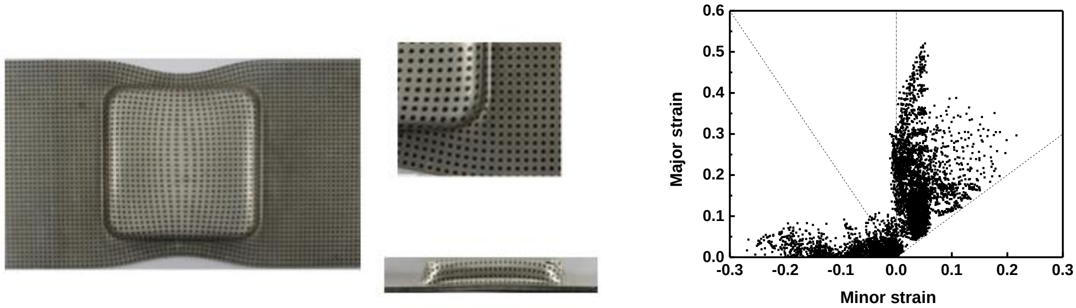
Pulse current assisted rectangular cup drawing tests for AZ31B were also conducted with various pulsing conditions. Punch and blank sizes are assigned as 60 × 60 mm^2 and 90 × 170 mm^2, respectively. In order to investigate the effect of the electrical pulsing on AZ31B, current density was changed from 50.0 A/mm^2 to 75.0 A/mm^2 while the pulsing duration and period were held constant value of 0.1 sec and 1.0 sec, respectively.

Fig. 6(a) represents typical load–displacement curves during conventional and pulse current assisted cup drawing tests. Similarly with Erichsen tests, The punch load decreased instantly once a pulsed electric current was applied. It is found that the cup drawing height increases when the electric current density increases while the other parameters keep the same. The maximum drawing depth of 10.01 mm is obtained when the current density increases up to 75 A/mm^2 while that is 2.85 mm under conventional drawing tests at room temperature.



(a) (b)

Figure 6. Pulse current assisted cup drawing tests for AZ31B with various electric current densities; (a) punch loads and displacement curves; (b) change of drawing depth



(a) (b)

Figure 7. Cup drawing tests with current densities of 75 A/mm^2: (a) photo of deformed sample; (b) major and minor strain distributions.

Fig. 7 illustrates the samples of AZ31 Mg alloy produced by pulse current assisted cup drawing tests at applying pulse current density of 75 A/mm^2. Major and minor strains are measured using DIC apparatus (ARAGUS). As shown in Fig. 7(b), the sample deformed under plane strain and stretch modes with maximum major strain of 40%.

4. Conclusion

In this paper, the effect of a pulsed electric current on the mechanical behaviors of a typical magnesium alloy, AZ31B, are investigated. Pulsed current assisted Erichsen cupping and rectangular cup deep drawing test of AZ31B are conducted with various pulsing conditions. The effect of pulsing conditions on the Erichsen index and cupping heights are discussed. The maximum EI of 11.7 is obtained when the current density increases up to 100 A/mm^2. It is found that the cup drawing height increases when the electric current density increases while the other parameters keep the same. The maximum drawing depth of 10.01 mm is obtained when the current density increases up to 75 A/mm^2 while that is 2.85 mm under conventional drawing tests at room temperature. It can be said that electrically-assisted forming technology for Mg alloy sheet is candidate to replace the warm forming technology. It is possible to preoccupy practical application technology to automotive component and commercialize its technology.

Acknowledgments

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