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Incremental forming of Mg alloy sheet at elevated temperatures

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Abstract

In the present study, incremental forming of Mg alloy sheet at elevated temperatures was attempted with local heating apparatus. The device is composed of several halogen lamps and designed to move with forming tool for local heating in deformation zone. In order to investigate the influences of process parameters to incremental formability of AZ31 alloy sheet, a series of incremental forming tests of AZ31 for cone and pyramid type of simple models were carried out under various process conditions. Experiments were performed under various temperatures, feeding depth per cycle and inclination angles and the results were analysed.

Keywords: Incremental forming; Mg alloy; AZ31; Formability

1. Introduction

Recently, as industrial demands for small quantity batch production product increase, the application of incremental sheet forming technology rises with the advantages of cost and time reduction in development of new items. Many studies related to incremental sheet forming technology have proceeded by earlier researchers and those can be classified into three categories: deformation analysis [1, 2], formability [3-8], tool path algorithm and the others [9-11]. However, incremental forming process for the sheet has not been done at elevated temperatures and thus its application is limited to the materials with high formability in room temperature. With its lightweight and high specific strength, Mg alloys have been widely used for structural components in the aerospace engineering, automobile and electronics industries. Due to its hexagonal closed packed structure, forming processes at elevated temperatures has been mainly studied. In the present study, incremental forming of Mg alloy sheet at elevated temperatures was attempted with local heating apparatus. The device is composed of several halogen lamps and designed to move with forming tool for local heating in the deformation zone. In order to investigate the influences of process parameters to incremental formability of AZ31 alloy sheet, a series of incremental forming tests of AZ31 for cone and pyramid type of simple models were carried out under various process conditions. Experiments were performed under various temperatures, feeding depth per cycle and inclination angles and the results were analysed.

2. Design and manufacturing of heating apparatus

In order to improve formability of AZ31 alloy sheet and expand its application area, heating apparatus for incremental forming was designed and manufactured. In design of heating device, three main factors were considered. The first, the device does not have to interrupt 3-dimensional tool paths. Secondly, rapid heating has to be possible to minimize process time. Thirdly, uniform heating inside of forming zone has to be possible. As a result of the approach, halogen heating device was designed as shown in Fig. 1. The

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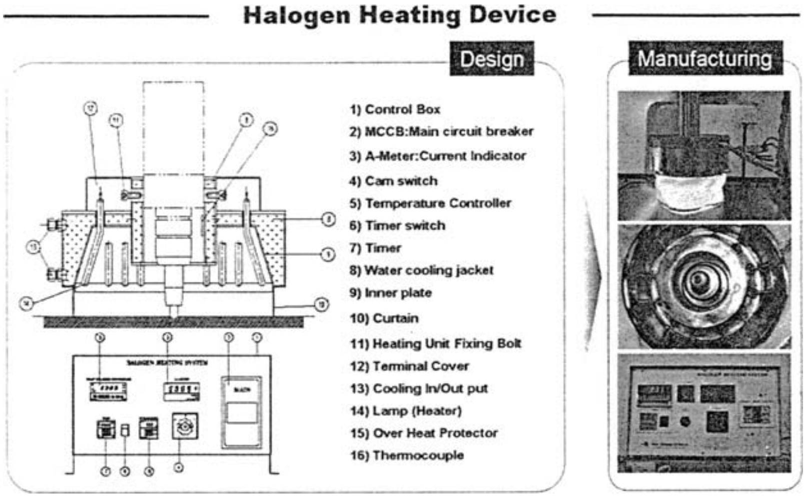
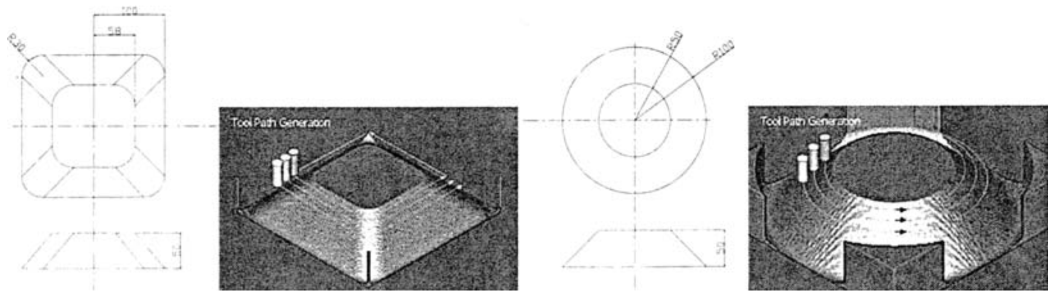


Fig. 1. Design and manufacturing of heating device for incremental forming at elevated temperatures.



(a) Model A (b) Model B

Fig. 2. Two types of test model and tool path generation.

developed device is composed of 'U' shape of 6 halogen ramps for rapid heating, control system for P.I.D control of temperature, water cooling unit to protect main forming machine against heat from deformation zone and heat resistant curtain to prevent heat transfer to outside. In addition, temperature is measured and controlled by two thermocouples attached on forming tool and material. Other details of heating device are summarized in Fig. 1

3. Incremental forming of AZ31 at elevated temperatures

To investigate the influence of process parameters to incremental formability of Mg alloy sheet, two types of simple models with the height of 50 mm were considered as shown in Fig. 2(a). AZ31 alloy sheet with 0.8t was chosen as test material and incremental forming CNC M/C was utilized. Halogen heating device was fixed to moving tool for local heating and incremental forming was carried out according to contour paths generated by CAD/CAM software as shown in Fig 2(b). Tool with diameter of 10mm and liquefied synthetic oil with auto ignition point of 400 were used. Forming velocity was 10 mm/s at the first stage for preheating and increased up to 100 mm/s gradually. A series of forming tests with different process parameters such as temperature, feeding depth per cycle and inclination angle were carried out to investigate the influences of those to formability in this process. Fig. 3 shows the incremental forming process at elevated temperatures.

3.1 The effect of feeding depth per cycle

First, experiments for different feeding depth per cycles [0.2/3mm] under the same other process conditions (T=250 , inclination angle θ=45°) were carried out. As shown in Fig. 4, as feeding depth is decreased, fracture height has a tendency to increase

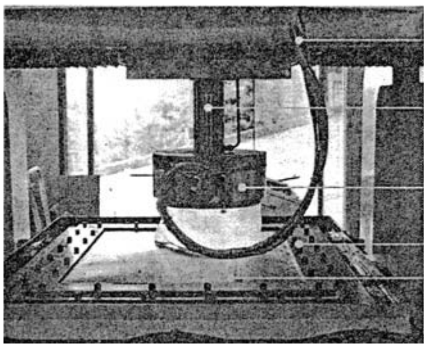


Fig. 3. Incremental forming at elevated temperature.

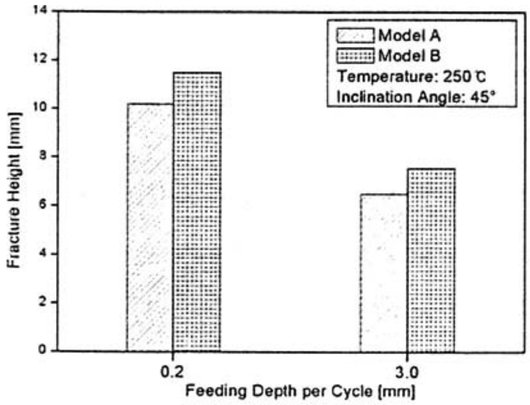


Fig. 4. Effect of Feeding Depth per Cycle.

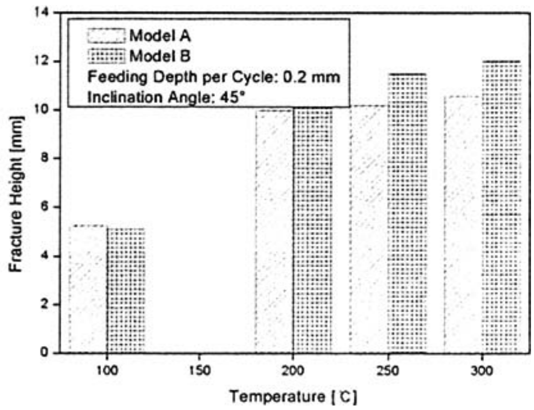


Fig. 5. Effect of Inclination Angle.

on the whole. And Model B shows higher fracture height than Model A at the same feeding depth. However, fracture occurred under 50 mm height in both cases.

3.2 The effect of forming temperature

Secondly, incremental forming tests were performed for various temperature ranges (100/200/-250/300) and other process parameters were fixed. In result, fracture height shows a tendency to increase as temperature goes up, but maximum fracture height at 300 is only 12.01 mm under designed height 50 mm. Fig. 5 shows experimental conditions and results.

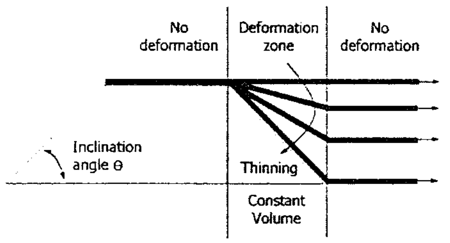
3.3 The effect of inclination angle

Since incremental sheet forming is a constant volume process, the material projects vertically downwards on the support and no more material comes into deformation zone as shown in left figure of Table 1. Therefore, high inclination angle causes excessive thinning of sheet material inside of the deformation zone. In order to examine the effect of inclination angle to formability, experiments for various inclination angles from 30° to 45° were carried out. Temperature and feeding depth were controlled to be constant as 250° and 0.2 mm. As shown in Table 3, fracture occurred before forming depth reaches 50 mm in the case that the inclination angle is over 35°. On the other hand, in the case that inclination angle is 30°, materials were deformed successfully up to 50 mm. Accordingly, maximum inclination angle to get successfully formed parts without any defect is about 30° in this case. And it is shown that inclination angel is the most important factor in warm incremental sheet forming process of Mg alloy than temperature and feeding depth. Figs. 6 and 7 show the experimental results.

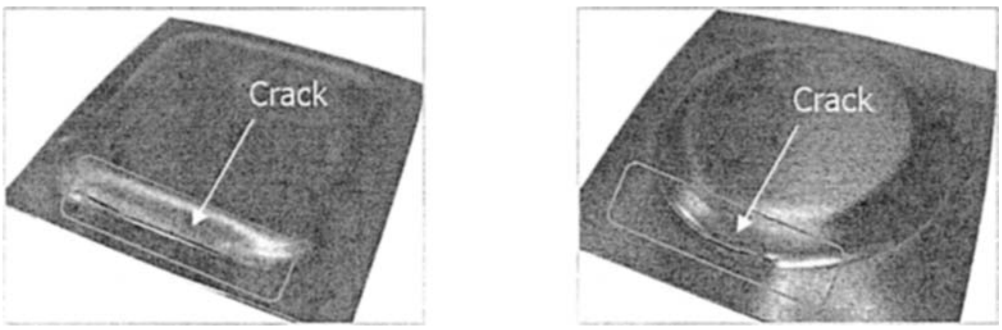
3.4 Measurement of Dimensions

To investigate the dimensional accuracy of two different models, 3D coordinate measurement system was used. As shown in Fig. 8, in the case of Model A,

Table 1. Effect of inclination angle to formability.

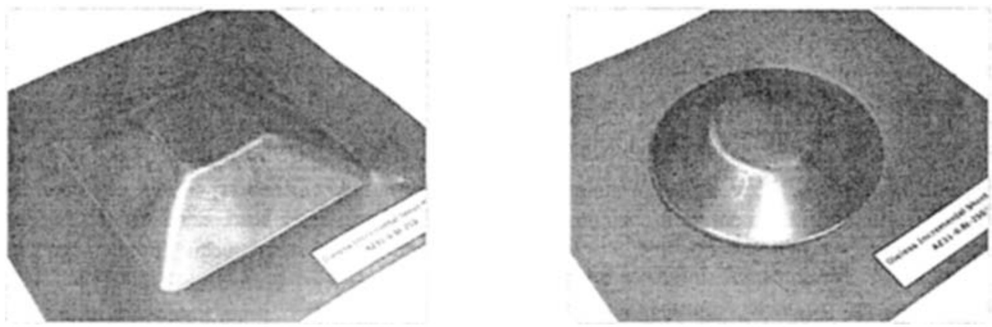


θ	Model A	Model B
45	Fracture	Fracture
40	Fracture	Fracture
35	Fracture	Fracture
30	Success	Success



(a) Model A (b) Model B

Fig. 6. Experimental results: crack occurrence (T=250 , Inclination angle=45).



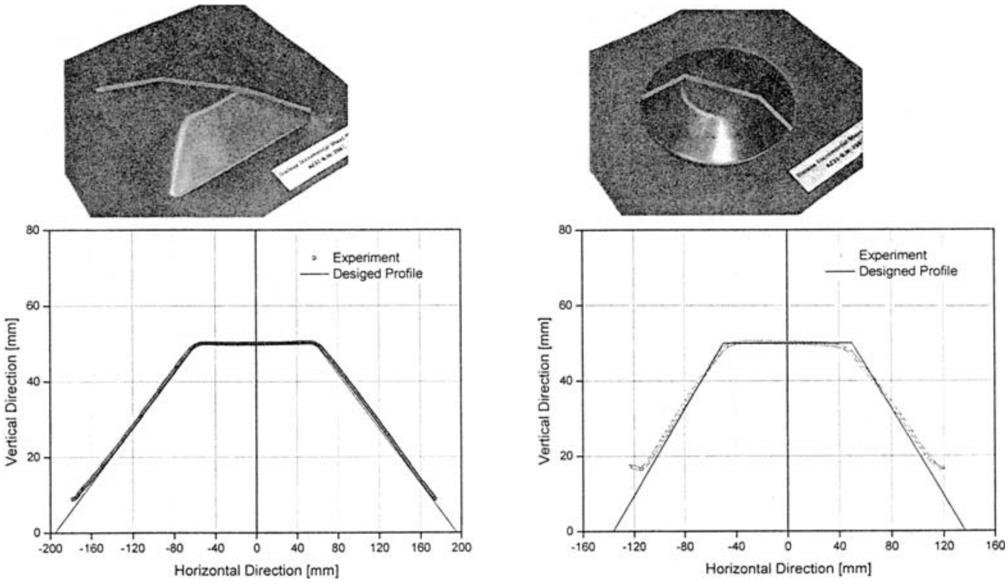
(a) Model A (b) Model B

Fig. 7. Experimental results: successful forming (T=250 , Inclination angle=30).

measured dimension of diagonal line shows a good agreement with the designed profile. However, in the case of Model B, it shows quite different tendency to design at corner part. It can be explained that square type of Model A is fixed well by 4 corner parts throughout the forming process but circular type of Model B allows the material to move slightly by friction force between the tool and material.

4. Conclusion

In this work, heating apparatus for incremental sheet forming at elevated temperatures was developed, and it applied heat to sheet material up to desired temperature ranges successfully and finally enhanced the formability of AZ31 sheet. In order to investigate the influences of process parameters to incremental formability, a series of forming tests under different process conditions were carried out. Among three process parameters considered in this study (feeding depth per cycle, temperature and inclination angle), the third one is the most dominant factor that decides successful forming or failure. Consequently, it is expected that incremental forming technology can be



(a) Model A

(b) Model B

Fig. 8. Results of 3-D coordinate measurement.

applied to the materials having poor formability and its industrial applications can be expanded.

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