A Study on Contour on Workpiece According to the Shape of Forming Coil in EMF Process

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Abstract

Aluminium alloys is desirable for the automotive and electronic appliances industries due to their high strength-to-weight ratio, corrosion resistance and weldability. However applications of the aluminium alloys were very difficult because aluminium alloys formability is very low at room temperature, despite their advantages. One of the high speed forming technologies is Electromagnetic Metal Forming (EMF), which can be useful forming method for low formability light-weight materials such as aluminium, magnesium alloys in overcoming the limitations of conventional forming methods. EMF process refers to the high velocity and high strain rate deformation of low-formability materials driven by electromagnetic forces that are generated by the rapid discharge current through forming coil. This technology depends on the properties of the sheet metal, as well as the process factors such as electromagnetic force in a practical forming operation. Moreover selection of proper shape of forming coil is most important to achieve the desired deformation using the EMF process. Therefore, the purpose of this study is to analyse of the dynamic behaviours on workpiece according to various forming coil shape with aluminium alloys. To achieve these objectives, a magnetic pulse forming system consisting of a 24kJ electromagnetic power source and a bar-type and helical-type forming coil was employed in an experiment. Then, deformation depth was measured for analyse dynamic behaviours on workpiece. The results showed that as the electromagnetic force increases, surface damage to part of the workpiece will increase and according to the shape of forming coil, distribution of electromagnetic force applied on workpiece is changed in EMF process.

Keywords

Aluminium alloys, Forming, Electromagnetic Metal Forming(EMF), Electromagnetic force

1 Introduction

Aluminium alloys is useful light-weight materials which have been employed in many forms such as sheet, plate, bar and rod in various areas of industry and especially in the automotive and small digital electronic product industries. Aluminium alloys also has many advantages included corrosion resistance and very good thermal and electrical conductivities. Although the aluminium alloys has high strength-to-weight ratio and good corrosion resistance, the low formability of aluminium sheets limited their use in some products with bending radius in the corner part is small. For expanding use of these aluminium alloys in many areas, however, there have been challenging formability problems for aluminium alloys to overcome. The formability of the aluminium alloys at room temperatures is generally lower than at both cryogenic and elevated temperatures [1-3]. For this reason, hot press forming is utilized as the forming process for aluminium alloys. However, hot press forming is not easy to determine the proper temperature of the die and considerably long process times is required for the post-process after forming. Therefore, it is necessary to develop an effective forming technology for aluminium alloys that can be used at room temperature.

Generally, a high current impulse in EMF has been passed through a forming coil by the discharge of a capacitor bank. The current in the forming coil also produced a transient primary magnetic field around the forming coil[4]. The change in this field induces an eddy current in the workpiece and an associated secondary magnetic field. The two fields are repulsive and the force of magnetic repulsion causes the collision between workpiece and die. When the stress arising from repulsive magnetic pressure exceeds the yielding point of the workpiece, plastic deformation of the workpiece begins. Because this repulsive force causes a rapid motion of the workpiece, light-weight material's formability is to improve instantaneous [4-7]. So EMF technology allows product designs which cannot be solved with conventional processes such as press forming. Moreover, this process is environmentally friendly forming process because environment pollutant such as lubricant, polyethylene etc does not need to use.

EMF has so far been studied many experimental and numerical analysis not only to promote increased formability, suppress wrinkling and reduced spring back, but also to improve the surface finish by Daehn et al. [6]. Balanetihiram et al. [7] represented the improvement of formability as follow;

(1) The workpiece constitutive behaviour changes at high-strain rates, leading to an increase in the rate of strain hardening and/or rate sensitivity

(2) It is possible that inertial effects promote more diffuse neck development, hence leading to higher ductility

(3) The collusion with die causes the material to plastically spread radially in a process that may be thought of as "inertial ironing".

During the past few years, several experimental and numerical studies have been performed for the EMF process.

Furth and Waniek[8-9] attempted to develop an analytical method using firstly. In that study, basic equations that describe the physical phenomena on EMF process established. Also Takatsu et al.[10] described the basic equations to simulate the electromagnetic free bulging of a fleet sheet. Work by Fenton and Daehn[11-12] demonstrated that a two-dimensional Arbitary Lagrangian Eularian(ALE) finite difference code has accurately been employed to predict the dynamics of the EMF process. With the development of commercial finite element codes, another approach has been proposed by Oliveira et al.[13] which developed a simple 'loosely coupled' model to simulate sheet EMF process. Shortly afterward, stiemer et al.[14] proposed a 'fully coupled' model to simulate the EMF process. The 'loosely coupled model or the 'fully coupled' allows accurate simulations of the EMF sheet process.[15] In that study, they investigated dynamic behaviour of aluminium alloy sheet with double spiral coil and then, major and minor engineering strains of workpiece predicted using the numerical FE-model. Also Bendjima[16] considered force due to motion of the workpiece utilizing two-dimensional finite element techniques to model the transient phenomena in EMF. As experimental works, Imbert et al.[17] examined the effect between tool and sheet interaction on damage evolution in EMF through free-form and conical die experiments. Kamal et al.[18] examined aluminium micro-embossed cell phone case by a two-step EMF process using uniform pressure (UP) actuator. In the first, an attempt has been made to form as enclosure body in single step using the UP actuator and then the fundamental embossing characteristic of the UP actuator system are demonstrated with very simple flat forming coil. As mentioned above, studies of EMF process has been focused on development of FE-model for prediction the forming process and process optimization for application of aluminium alloys. However, these experimental and numerical studies did not compare the dynamic behaviours of workpiece according to various forming coil shapes. Therefore, this study concentrated on analysis of the contour on workpiece when employed the various shape forming coil with aluminium alloys in EMF process. In order to achieve this objective, EMF was performed using a bar-type forming and helical-type forming coil and 0.5mm Al5053 sheet at various charged voltages, and then the results were compared through measurements of the deformation of depth on workpiece.

2 Experimental Works

2.1 Experimental Setup and Procedure

As shown in Figure 1, EMF system which manufactured by WELMATE CO.,LTD. for this study includes a magnetic pulse power source which consists of a capacitor bank with a maximum charging energy of 24kJ, a forming coil and a die.

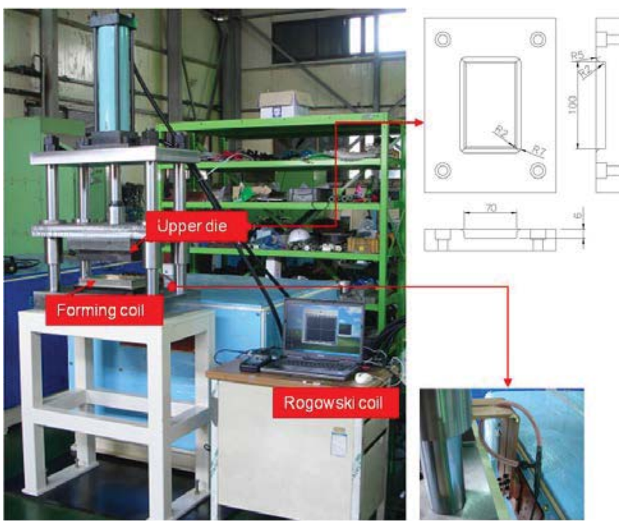
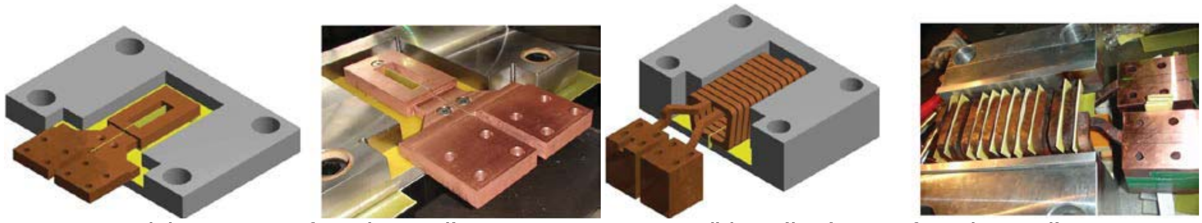


Figure 1: *Set up for this study*

For the forming coil, as shown in Figure 2, a bar-type (a) and helical-type (b) forming coils were designed and manufactured using beryllium copper and then insulated using epoxy. Additionally, in order to observe a discharge waveform and peak current, Rogowski coil was installed around the magnetic pulse power source and the forming coil as shown Figure 1. The specimens employed were each 0.5mm of Al. The product for this study was chosen the rectangular box with a 6mm depth, 2mm radius. Also the blank holding force is 130kN. The forming was done by discharging the capacitor after charging it to 4, 5, 6kV using the charging voltage control switch of the magnetic pulse power source after the setup process. An analysis was made after forming of the formability by measuring the deformation of depth on workpiece. Depth on workpiece was precisely measured using a 3D scanning.



(a) Bar-type forming coil (b) Helical-type forming coil

Figure 2: *Two type forming coil*

2.2 Results and Discussion

When bar-type forming coil used in EMF process, the damped sinusoidal waveform was measured. Also the time until the peak current was measured 30us. The minimization and maximization values of the peak current were 57.5kA and 77.5kA respectively. According to the result of the observation of the workpiece, the deformation increased as the charged voltage increased as shown in Figure 3.

(a) 4kV (b) 5kV (c) 6kV

Figure 3: *Results of EMF with bar-type forming coil*

Particularly, damage in the shape of a circle was observed on the surface of the workpiece. This damage was generated when the workpiece collided with the die at a depth of 6mm due to electromagnetic force. Figure 3(a) and (b) show the damage on the workpiece at 4 and 5kV. On the other hand, as shown in Figure 3 (c), two surface damages were observed at 6kV, and the damage was more serious on the inside than it was on outside. The electromagnetic force affecting the workpiece increases according to the increase of the charged voltage and the surface damage from the rebound after the collision between the workpiece and the die. This rebound on workpiece was reported by Beerwald et al.[19] which predicted the workpiece collides with the die by electromagnetic force at the point of the initiation of deformation. And Kamal [20] reported that air caused the rebound at the workpiece and the subsequent collision with the die. As mentioned earlier, magnetic pulse forming process is very fast and the process ends in less than 100us. When instantaneously electromagnetic force is applied the workpiece, the air present in the die does not have enough time and area to leave the die and thus causes the rebound and the consequent surface damage. However, the perfected theoretical analysis for rebound effect hasn't been established yet.

When helical-type forming coil used in EMF process, the damped sinusoidal waveform was also measured. But the time until the peak current was observed 100us by Rogowski coil and the minimization and maximization values of the peak current were 85.2 and 98kA respectively. Figure 4 shows the result of deformation on workpiece after EMF process with helical-type forming coil. The deformation increased as the charged voltage increased. But deformation is tending more uniform than deformation when used bar-type forming coil. Especially, there is no rebound on workpice at 6kV as shown Figure 4(c).

(a) 4kV (b) 5kV (c) 6kV

Figure 4: *Results of EMF with helical-type forming coil*

To analyze the dynamic behaviour on workpiece with two type forming coil, deformation depth was measured at 4kV and 5kV in the direction of the x-path from the center of workpiece. Figures 5 and 6 shows the deformation height on workpiece in EMF with bar-type and helical-type forming coil at 4kV and 5kV respectively. As shown in Figures 5 and 6, the deformation increased according as the charged voltage increases. Especially, when charged voltage was at 4kV, the rebound was not observed, but hardly gets the rectangular box shape. Also the curve which used helical-type forming coil was more fluent than curve with bar-type forming coil in EMF. According to these results, helical-type forming coil is more effective than bar-forming coil in EMF. These results represent that the shape of forming coil is most important factor in EMF process. Distributions of electromagnetic force to apply on workpiece were changed by the shape of forming coil and then it lead to different dynamic behaviours on workpiece.

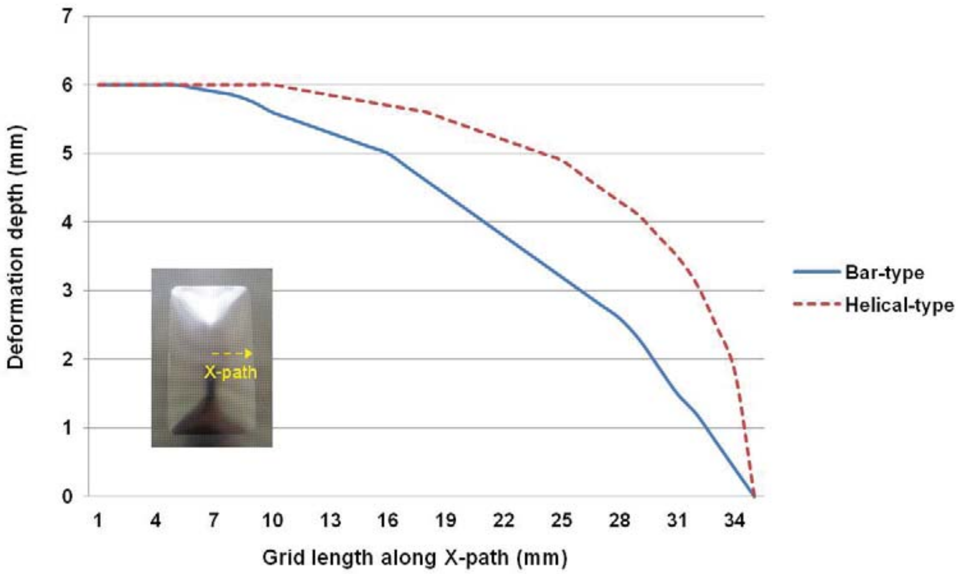


Figure 5: *Deformation depth on workpiece at 4kV*

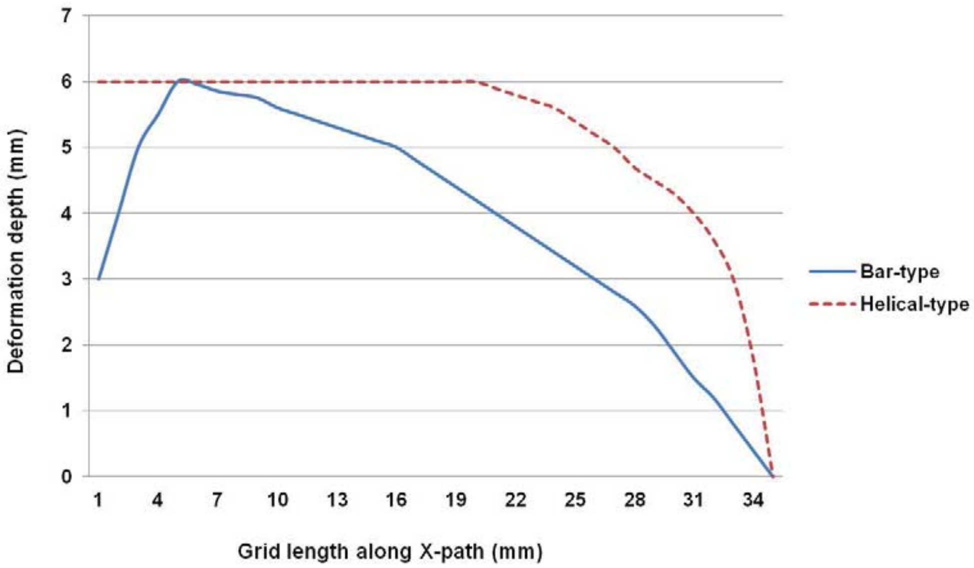


Figure 6: *Deformation depth on workpiece at 5kV*

3 Conclusions

This research was concentrated analysis of the contour on workpiece when employed the bar-type and helical-type forming with aluminum alloys in EMF process and reached with the following conclusion.

(1) Surface damage from the rebound after the collision between workpiece and die was observed on workpiece in EMF with bar-type forming coil especially the number of rebound was increased as charged voltage increases.

(2) To achieve successful forming for rectangular box product, helical-type forming coil is more effective than bar-type forming coil in EMF process.

(3) According to the shape of forming coil, distributions of electromagnetic force on workpiece have been changed in EMF process because non-uniform of distributions of electromagnetic force was lead to non-uniform forming.

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