A novel forming method of aluminum sheet based on superposition principle of electromagnetic local forming

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Abstract: A novel forming method aimed at large size aluminum sheet is introduced. In this method, aluminum sheet is clamped between a common flat spiral electromagnetic actuator and a punch matrix. Driven by pulsed electromagnetic force and restrained by punch matrix, the blank sheet will form local shallow dome accordingly. Moving actuator along sheet surface and triggering the pulsed power generator in sequence results in dome matrix that is uniformly distributed. Superposition of those spherical domes leads to macroscopically curved figuration of aluminum sheet. This paper demonstrates the newly proposed method experimentally, which verifies its feasibility. The mechanism analysis of this method is also presented using a simplified analytical model. The results show that this novel method is feasible and can be explained by the proposed mechanism well.

1. Introduction

Electromagnetic forming process is one of high speed forming processes. Compared to conventional quasi-static forming operations, researches show that formability of metallic materials such as steel [1], aluminum alloy [2], magnesium alloy [3] and titanium alloy [4] is dramatically improved due to the high speed of this forming process. Furthermore, it can inhibit springback of workpiece significantly. More detailed advantages are concluded by Psyk V et al. [5].

A lot of researchers are interested in electromagnetic forming field because of those advantages. However, limited by electromagnetic actuator and capacitor bank, they lack research on electromagnetic forming of large scale workpiece. Cui X et al. [6] proposed a novel electromagnetic incremental forming for aluminum alloy sheet and tube. The results show that this newly proposed technology is feasible for the manufacturing of large parts.

This work also aims at forming large scale workpiece using pulsed electromagnetic force. A novel forming method of aluminum sheet based on the superposition principle of electromagnetic local forming is proposed. A regular electromagnetic coil and punch matrix that is used in multi-point forming technology [7] are adopted in this method. Different from the former work [6], no macroscopic deformation appears during the forming procedure. The specimen becomes cambered only if it is released from clamps after this procedure.

This paper demonstrates the novel forming method using detailed experimental procedure. Deflections and several sectional profiles of the specimens are measured too. A simplified qualitative analysis model is then adopted to illustrate the mechanism of this newly proposed forming method.

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2. Experiments

2.1. Experimental procedure

As shown in figure 1, during experimental procedure, the clamps fasten specimens and keep them horizontal. Actuator and punch matrix are then positioned along the length direction of sheets synchronously. Once they are positioned correctly, the pulsed power generator will be triggered and the electromagnetic local forming at that position is accomplished. Moving those tools to next position and triggering the generator again, and so forth. The synchronous feeding distance of actuator and punch matrix is input into PLC by a Human Machine Interface and detected by a grating scale, respectively.
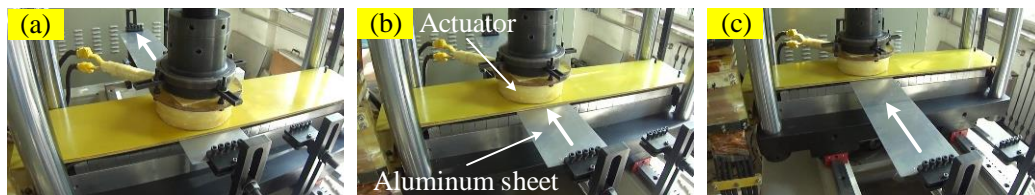

Figure 1. Positioning procedure of experiments. Beginning position (a), middle position (b) and ending position (c). The thicker arrows mark the positioning direction.

2.2. Experimental parameters

The 2xxx series of aluminum alloy are widely used in aerospace field because of their nice comprehensive properties. Thus 2524-T3 aluminum alloy sheets were then investigated in this work. Dimensions of the specimens were set to be 900mm×150mm×1.6mm. Table 1 shows more detailed parameters. Because effective outer diameter of the actuator (149mm) and width of the sheets (150mm) are almost the same, the actuator and punches were not moved along the width direction of sheets. They were kept symmetry with specimen in that direction during the forming procedure.

Table 1. The detailed parameters of forming experiments.

No.	Discharging voltage (V)	Feeding distance (mm)	Cushion thickness (mm)	Epoxy sheet thickness (mm)
1	2500	30	2	10
2	5500	30	8	10

3. Results and discussions

Figure 2 shows the figuration of specimens. The clamping allowances of these specimens were trimmed away. Thus only the deformed part of each specimen is exhibited, which is in the size of 600mm×150mm×1.6mm. The specimen number is in accordance with experiment number listed in table 1. An undeformed sheet is inserted to illustrate deformation of specimen vividly. According to this picture, these two specimens bend towards different directions. Specimen 1 bends towards the punches side while specimen 2 bends towards the coil side. The maximum deflections of specimens are amplified and demonstrated on the right side. It shows that specimen 1 has smaller deflection which approximately equals 9.5mm. And specimen 2 approximately reaches 15.5mm.

In order to analyse forming mechanism, detailed surface features are then taken into consideration. Specially, some profiles are extracted along several certain paths. A hand held laser scanner is used to obtain the three dimensional coordinate data of these specimens in STL format. Importing the files into commercial 3D CAD software CATIA, the reconstitution models and extracting paths are demonstrated in figure 3. The paths are located in the surfaces adjacent to coil. A shallow dome matrix can be observed on specimen 2 in case of careful observation.

Based on the extracted point cloud data, two sectional profiles are then fitted by high order curves. The maximum deviation between point cloud and fitted curve is set to be 0.03mm because of the

measuring accuracy of laser scanner. Figure 4 shows the porcupine curvature analysis of these profiles. The profile number is in accordance with path number shown in figure 3.Comb length represents the curvature magnitude at that point. And the combs are shown in outward normal direction of each sub-segment. Some extremum values are labelled.

Macroscopically, profile 1 is a concave curve while profile 2 is a convex curve. However, the wavy envelop of combs means that these profiles are not smooth enough but locally wavy. For profile 1, sub-segments such as 1a, 1c, 1e, 1g and 1i have smaller curvature than the adjacent segment. On the contrary, for profile 2, sub-segments such as 2a, 2c, 2e, 2g and 2i have larger curvature than the adjacent segment. It should be noticed that the macroscopic bending direction of each profile is in accordance with sub-segment that has larger curvature. Generally, profile 1 has smaller curvature than profile 2, which means it is smoother.
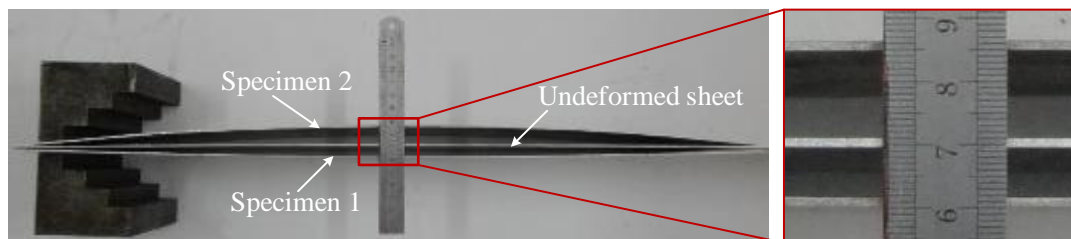

Figure 2. Figuration of the specimens. These specimens bend towards contrary directions and reach different deflection magnitude.
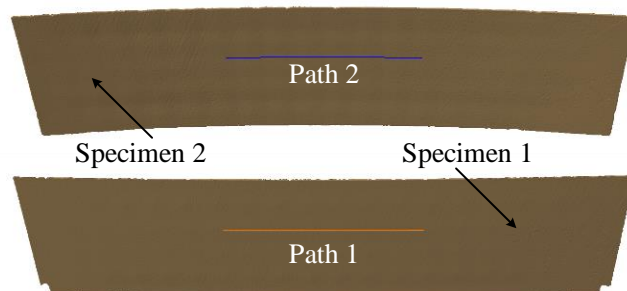

Figure 3. This figure shows the reconstitution models of specimens and the corresponding extracting path. Shallow dome matrix can be observed in specimen 2.
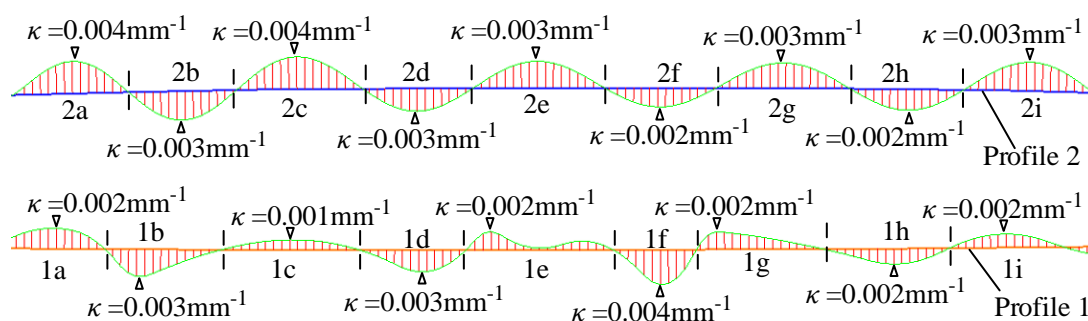

Figure 4. Porcupine curvature analysis of the profiles.

Base on the extracted sectional profiles, a simplified schematic mechanism diagram of this method is demonstrated in figure 5. It shows a part of the cross section of aluminum sheet during forming procedure. The rubber cushion is omitted. Furthermore, this section is divided into several subsections. Subsection 1 and subsection 2 bend towards contrary directions. The neutral surface radii of these subsections are represented by R and r, respectively. It should be noticed that curvature κ is the reciprocal of radius R or r.

According to theory of plates and sheets, smaller radius leads higher bending stress. It means that subsection is easier to generate larger plastic deformation magnitude. The forming mechanism depends on the relative magnitude relationship between R and r. In case that R is bigger than r, subsection 1 will generate smaller plastic deformation while subsection 2 gets a bigger one. When the symmetric boundary condition is released, this section will bend towards the punches side. Superposition of these local bending lead macroscopic deformation of the specimen, which also bends towards the punches side. Similarly, if R is smaller than r, the specimen will bend towards the coil side.
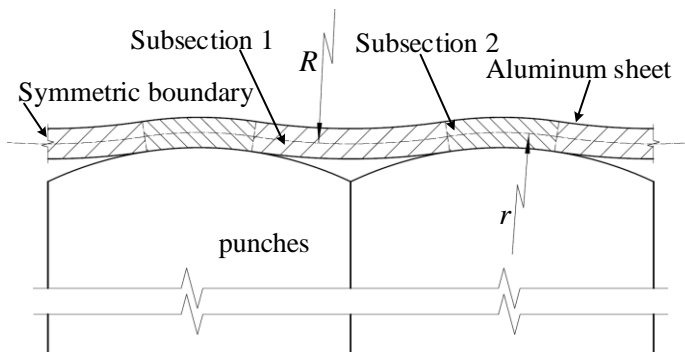

Figure 5. A simplified schematic mechanism diagram of this novel forming method.

This simplified qualitative model can be popularized to actual situation. During the forming procedure, sheets are driven by electromagnetic force and restrained by punch matrix. Because of spherical end of punch, local bulging with rigid punch is achieved. On the other side, a local electromagnetic bulging is also generated. They result in shallow domes when the bulging stress is large enough for plastic deformation. The final figuration of specimen is determined by superposition of these local domes and relative magnitude relationship between these neutral surface spherical radii. Based on the figurations of specimens shown in figure 2 and detailed information demonstrated in figure 4, the forming mechanism of this novel method is verified to be correct.

4. Conclusions
Based on the experiments carried out and the simplified analysis model, this forming method is feasible. Thus a novel forming method of aluminum sheet is proposed. It extends the application of electromagnetic force. Discharging voltage of capacitor bank and rubber thickness will determine the figuration of specimen. The effects of such parameters on specimen figuration and its surface integrity are prepared for further research.

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