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Electromagnetic incremental forming of integral panel under different discharge conditions

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ABSTRACT

A method for forming panels through the electromagnetic incremental forming (EMIF) process with coil shifting is presented in this study. The forming effect of the panels under different EMIF process conditions was explored through experiments. The results show that the two consecutive discharges method of a small voltage followed by a high voltage in a fixed position was helpful for improving the forming depth and shape deviation to die of the panel; the increase of the capacitance over a certain range was helpful for improving the forming depth; a large position distance was beneficial to improve the forming depth; and a loading path of "side-midst-side" with a large discharge voltage in the subsequent position could effectively improve the forming depth and shape deviation to die. These forming rules show that EMIF is feasible for forming panels using a suitable loading path with reasonable capacitance and discharge positions combined with two consecutive discharges of a small voltage followed by a high voltage in a fixed position.

1. Introduction

With the development of advanced equipment in the fields of aeronautics and astronautics, it is necessary to expand the transport capacity, reduce energy consumption and increase the service life of the advanced equipment. For these requirements, thin-walled, lightweight and complicated components are needed. Because of their light weight, high stiffness and high structural efficiency, integral panels with high-stiffener have become important structural bearings of modern advanced aircrafts and widely used in modern aircrafts as demonstrated (e.g., [1]). Conventional forming processes for integral panels include shot peen forming, press bending, creep age forming, etc. Shot peen forming is a process by which bombarding the surface of a metal sheet with a stream of small hard shot with sufficient kinetic energy can form a specific shape, and has been used especially for contouring integral aircraft skin panels as demonstrated (e.g., [2]). The peen forming process can be controlled by adjusting the process parameters, such as velocity, action area and spray angle. However, because it is subject to formability, shot peen forming is mainly used for forming simple rib structure panels and panels in which the rib is not high, such as in the peen forming of wing skins case study presented by Burmeister [3]. Creep age forming (CAF) uses materials in which creep can produce stress relaxation in the aging temperature, thus the materials gradually experience plastic deformation under the elastic loading. Eberl et al. [4] stated that CAF is one of the few processing techniques that has been proven by researchers to be viable for the production of extra-large integral airframe structures (IAS). This method offers the advantages of small springback and high forming precision. However, Zhang et al. [5] demonstrated that CAF of large panels only applies to materials with age hardening properties, thus the amount of springback of the panels after CAF is large, the fit between the panel and the die is poor, and the energy consumption and cost are high. Press bending is a process by which a die makes the panel bend under the action of mechanical pressure. The research of Munroe et al. [6] and Yan et al. [7] showed that Press bending has become an important method for manufacturing integral panels because of its many advantages, such as low tooling cost, short cycle time and adaptability to different contours. However, Yang and Wang [8] reported that press bending is operator-dependent and the process parameters should be chosen carefully to avoid buckling and fracture on stiffeners and to form the desired contour. Lang and Xu [9] claimed that in the panel press bending process, plastic deformation only produces on the top of the rib and the web always underwent elastic deformation. Furthermore, after bending, the panel exhibited large springback, which resulted in low precision of the final panel shape, thus it is difficult to meet the requirements of large integral panel parts.

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Electromagnetic forming (EMF) is an impulse or high-speed forming process using a pulsed magnetic field to apply Lorentz forces to workpieces preferably made of a highly electrically conductive material. During this process, there is even no working medium or mechanical contact between the workpiece and the dies as presented (e.g., [10]). Therefore, the cost of die manufacturing and production costs of EMF can be reduced. Because of its high deformation velocity, the formability limit can be increased and the production cycle can be shortened. In addition to the previous advantages, the required equipment of EMF is relatively simple, as demonstrated by Seth et al. [11] and Arumugam et al. [12]. Therefore, in the last few decades, an increasing need to produce high strength components more economically than by conventional forming processes caused a renewed interest in EMF, which has been widely used in the mechanical (e.g., [13]), electronic (e.g., [14]), automotive (e.g., [15]), aerospace (e.g., [6]) and other fields.

The coil and its position are fixed in EMF. Because of the inertia effects of sheet metal in the process of EMF, EMF with a fixed coil is limited in application to local forming (such as small fillet region forming) and deep drawing of some sheet metals. For this purpose, some researchers use coils that can produce different forming effects or methods that combine the EMF with some conventional forming techniques to solve these problems. The research of Kamal et al. [16] showed that the forming precision of the local details of the sheet could be improved by changing the coil in the EMF. Researchers at Ohio State University successively proposed Matched Tool-Electromagnetic (MT-EM) hybrid sheet forming, which was proposed by Vohnout [17], and Electromagnetically Assisted Stamping (EMAS), which is proposed by Shang [18] and Shang and Gaehn [19]. EMAS combines the advantages of conventional stamping and EMF, and has been applied to the forming of the AA6111-T4 aluminum alloy car door inner panel and the small fillet components by Imbert and Worswick [20,21]. With the requirements of large size and cost reductions, Cui et al. [22] proposed an electromagnetic incremental forming (EMIF) technology and Cui et al. [23] demonstrated its feasibility by changing the position of a single coil in the direction of three degrees of freedom to deep draw large aluminum alloy parts. Cui et al. [24] proposed an incremental electromagnetic-assisted stamping (IEMAS) technology with radial magnetic pressure and adopted it for the deep drawing of a cylindrical cup.

Considering the large size and complex shapes of integral panels, traditional EMF and EMAS are difficult to apply directly because of the limited action scope and depth of the magnetic field force from the coil with a fixed position. Therefore, it is necessary to form the integral panel through shifting of the coil, i.e., using EMIF (as shown in Fig. 1). Compared to traditional EMF, EMIF increases some of the new forming parameters, such as discharge position, discharge pass, loading path, coil overlap, etc., and there may be complex coupling effects among these new and common parameters. Therefore, EMIF is a more complicated process than EMF. At present, only a few researchers have conducted studies on EMIF. Zhao et al. [25] analyzed the forming uniformity under different coil overlap rates and different loading paths during the tube electromagnetic incremental bulging process. The results of this study showed that the higher the coil overlap rate, the better the forming uniformity, whereas the forming efficiency decreases. Cui et al. [26] proposed a new forming method named incremental electromagnetic assisted stamping with radial magnetic pressure to draw a deep cylindrical cup, and set up a 3D finite element model to predict the complex deformation process. The results showed that this method could significantly decrease the tensile stress and thickness reduction at the easily broken position, and obtain uniform stress distribution in comparison to traditional stamping. Cui et al. [21] analyzed the effect of coil moving path, discharge pass and discharge parameters on the electromagnetic incremental deep drawing of sheet metals. They reported that sheet components with good fit to the die were obtained by adopting reasonable process parameters. Furthermore, Cui et al. [27] analyzed the effect of the subsequent deformation on the deformed sheet region, material flowing and the strain distribution of the EMIF sheet forming process through 3D numerical simulations and experiments.

Because of the large scale and complexity of the integral panels, it is necessary to adopt EMIF. The characteristics of large size, high ribs, and high structural rigidity, especially the complex and staggered high ribs grid structure, of integral panels lead to forming mechanisms and laws in EMIF that are different from those of pipes and metal sheets in EMIF. Therefore, it is vital to study the EMIF process of integral panels. This report studied the forming effects of a panel under different capacitances, discharge passes, loading paths, position distances and panel structures to explore the feasibility of forming large integral panels by EMIF.

2. Experimental materials and methods

2.1. Materials and blank

The experimental material used in this paper was 2A12-T4 aluminum alloy. Because ribs with a grid shape structure are always applied in aircraft panels, a grid ribs stiffened panel blank was designed in this study, as shown in Fig. 2. The main forming region is located in the middle of the blank, which has dimensions of

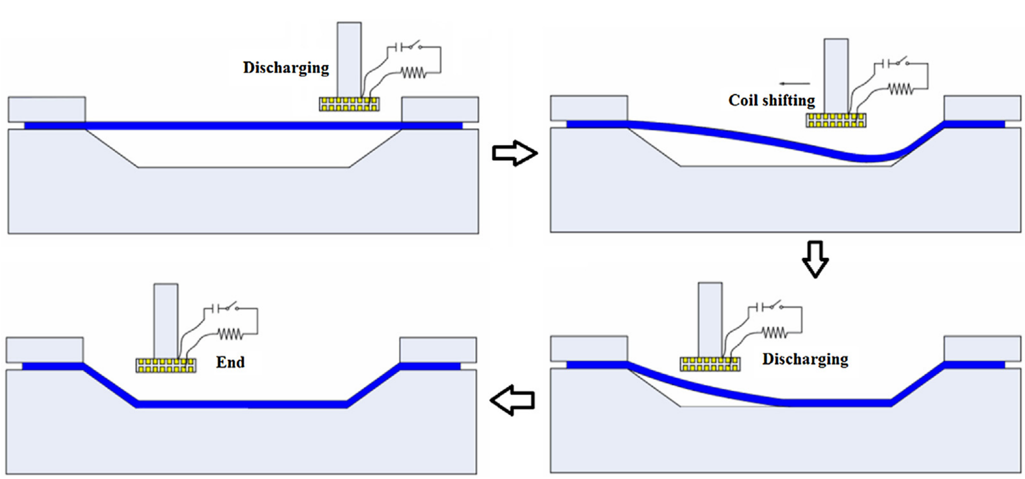

Fig. 1. Schematic of the EMIF process.

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