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Large-scale sheet deformation process by electromagnetic incremental forming combined with stretch forming

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ABSTRACT

Large-size sheet parts manufacturing requires huge forming machines in spinning and sheet hydroforming. In addition, large part cannot be shaped by conventional electromagnetic forming method due to the limitation of the strength of working coil and the capacity of capacitor bank. In this paper, a new method denoted as electromagnetic incremental forming combined with stretch forming is proposed, which was adopted for manufacturing large-size and thin-walled ellipsoidal parts. A 3D finite element model is established to analyze the effect of the number of coils, coils moving path on forming quality. The effect of the subsequent deformation on deformed sheet region, material flowing and the distribution of stress in special elements are also discussed. Then, the experimental platform designed based on FEM is used to manufacture the large-size parts after 36 times discharging and 6 times stretching. The simulation has a good agreement with experiment results. In comparison with single point incremental forming, the thickness thinning is sharply decreased using the new method.

1. Introduction

To ensure a high efficiency, low fabrication costs and a high flexibility of manufacturing processes, the development of sheet metal forming processes is directed towards the fabrication of large-size, thin-walled sheet metal parts with deep cavities. Up to now, there are mainly two methods for large-scale sheet deformation: spinning and sheet hydroforming. The first method is widely used for manufacturing axisymmetrical, thin walled thickness and hollow circular cross-section parts. A recent very detailed review by Xia et al. (2014) showed metal spinning has several advantages, such as low forming loads, simple tooling, good dimensional accuracy, and improved mechanical properties due to the nature of localized material deformation. Li et al. (2014) described the currently vertical spinning machine with 1000 kN in China has the following dimensions: a length of 20 m, a width of 18 m and a height 13 m. It can be used to manufacture axisymmetric bodies with a maximum diameter of up to 2.6 m. The second method is a combination of conventional deep drawing and hydroforming, comprising the advantages of both technologies. During the forming process, the liquid will flow between the sheet metal and the die to produce liquid lubrication, which can reduce the friction in the blank flange area. Currently, Yuan et al. (2015) is building the 150 MN hydraulic forming machine, which exhibits the world's largest tonnage. The size of the working platform of this machine is 4.5 m × 4.5 m, and its height is 19.5 m. Apparently, the manufacturing of large components requires huge forming machines.

Low-density materials with a high strength, such as aluminum alloys, are preferably used in the automotive, aircraft and aerospace industry to improve the fuel economy and reduce environmental pollution. However, in conventional forming processes, the forming limits of aluminum alloys are usually much lower than the forming limits of steel. Furthermore, a high springback usually occurs when forming aluminum because it has a lower elastic modulus than steel, which decreases the dimensional accuracy during forming. Therefore, the high-precision manufacturing of large thin-walled structures using aluminum alloys has become a common scientific and technical challenge that needs to be solved.

In the past few decades, several studies have indicated that the formability of aluminum alloy increases when formed using high-speed processes, e.g., electrohydraulic forming (EHF), explosive forming (EF) and electromagnetic forming (EMF), due to strain rate and inertial stabilization. For example, Balanethiram and Daehn (1994) reported a significant increase in formability for the AA 6061 when formed by EHF, and Imbert et al. (2005) demonstrated an increased formability when an AA 5754 sheet was formed into a conical die by EMF.

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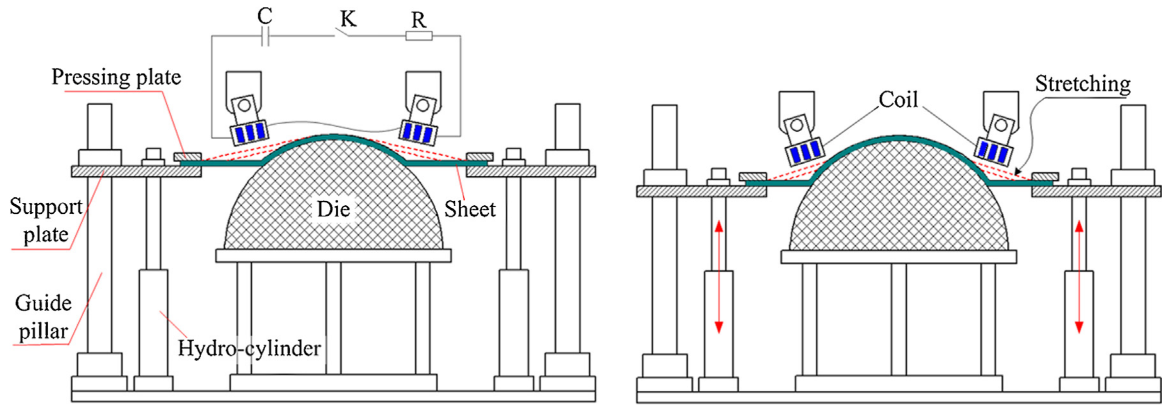

Fig. 1. Schematic illustration of the combined EMIF/SF forming process: (a) forming of the 1st layer and (b) the next layer.

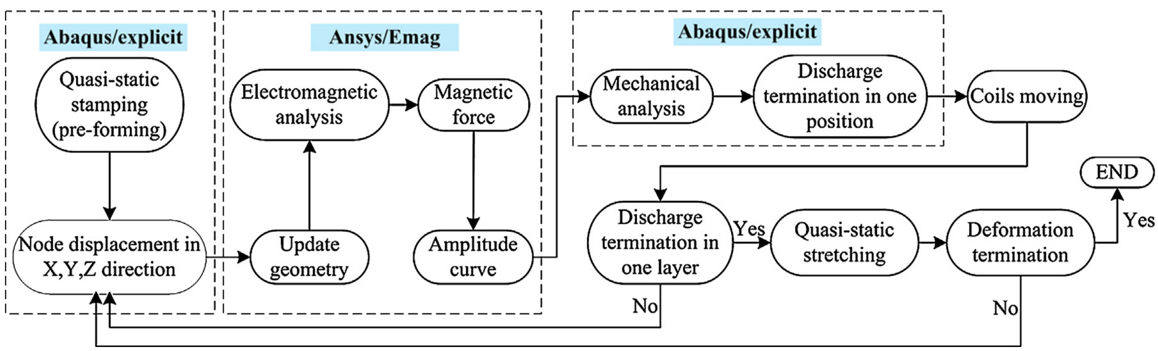

Fig. 2. Flowchart of the numerical calculations performed for the combined EMIF/SF process.

EMF is one of the most widely applied high-speed forming methods, which can speed up the workpiece deformation process by applying a magnetic force according to the electromagnetic induction theorem. Up to now, EMF has been used for sheet/tube forming, joining, welding, cutting, and the calibration of parts. Kamal et al. (2007) utilized electromagnetic forces in a two-step method to make a decent phone face. Jäger et al. (2011) developed a novel process chain by integrating the aluminum extrusion and an EMF compression process to locally reduce the cross-section of the workpiece to meet industry requirements to some extent. Yu et al. (2014) found that Bi-metal tubes can be manufactured by magnetic pulse cladding. This method can be used to form sound cladding bounds and can also be adopted to produce tubular clad components with a high axial length. Although EMF offers many

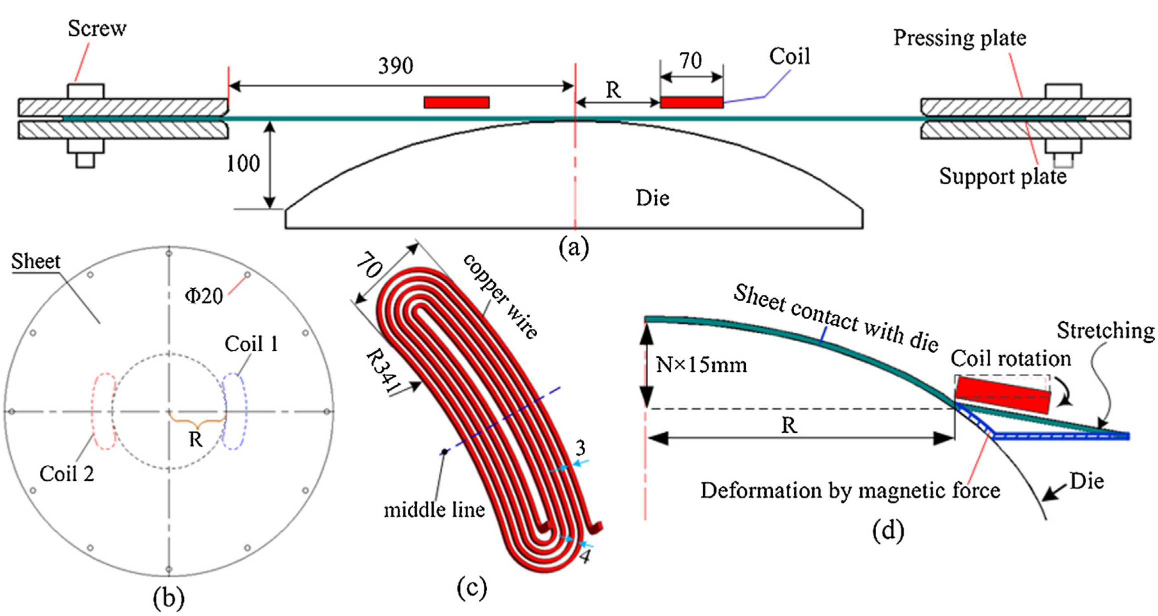

Fig. 3. Schematic illustration and dimensions of the geometric model (in mm) used to simulate the forming process: (a) forming system, (b) sheet metal, (c) double symmetric coils, (d) coil position for the $(N+1)^{th}$ layer.