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A comprehensive electromagnetic forming approach for large sheet metal forming

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Abstract

By exploiting the potential advantages of electromagnetic forming, a comprehensive approach has been developed for large sheet metal forming. In this study, this approach was applied to form an aluminum alloy sheet into partial-ellipsoid shape. The sheet is with a diameter of 1378 mm, and a thickness of 3.945 mm. Compared to conventional forming process, the forming facility is very light-weight, and has following dimension: a width of 1840 mm, a length of 1840 mm, and a height of 1800 mm. An experiment was performed to evaluate the forming quality obtained by the proposed facility. The profile of the formed sheet was measured and fitting with the die profile to assess the deviation between the formed sheet and the desired shape. About 60% of the sheet area has the deviation with the desired shape less than 1 mm. The thickness was measured to evaluate the thinning of the formed sheet. The maximum thinning over the ellipsoid surface of the formed sheet is only about 9.48%. This study proves the feasibility of the proposed process, which provides a cost-effective method for large sheet metal forming.

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Keywords: Large sheet forming, Electromagnetic forming, Lorentz force, Forming cost, Forming quality.

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1. Introduction

Manufacturing large and thin-walled sheet metal parts has great significance for aerospace, automobile, and lots of other industries. Shaping large parts with quasi-static forming process, however, generally requires huge forming machines, since the high quasi-static forming loading needs to be constrained. For example, a 1000 kN spinning machine that can shape 2.6 m sheet metal has a length of 20 m, a width of 18 m, and a height 13 m [1]. A 150 MN hydraulic forming machine that is being built with the capability to manufacture 4 m sheet metal has a height of 19.5 m [2]. The huge forming machine results in high production cost, which is a great challenge for large-scale sheet metal forming, especially for small batch production.

In addition to the high production cost, the control of the forming quality is another challenge. Firstly, due to the increasing applications of light-weight metals, which generally have relative poor room temperature formability compared with mild steel [3, 4], the sheet metal tends to neck or tear at relatively low strain levels, making the forming of complicated parts difficult. Secondly, it is difficult to effectively control the wrinkling of the sheet area without normal constraint, especially for sheet metal parts with very thin-walled [5, 6].

Few forming processes can simultaneously overcome the challenges of high production cost and difficult control of forming quality in large sheet forming. For example, sheet hydroforming process [5, 7, 8] can provide sound forming quality, but requires high tonnages hydraulic machine, which is expensive. Incremental forming (IF) as a flexible forming process can significantly reduce the production cost, however, the severe thinning and the limited geometrical accuracy directly lower the forming quality [9].

Electromagnetic forming (EMF) is a potential alternative approach that can shape large sheet metal with sound forming quality and relative low production cost. Different to quasi-static forming process, such as hydroforming, electromagnetic forming process is a high speed dynamic process shaping sheet metal with high pulsed Lorentz force. Therefore, only one-side die is needed, which can reduce the tool cost [10]. Furthermore, in EMF process, the deformation speed of the workpiece can be up to several hundred meters per second, and the deformation duration can be as low as several hundred micro-second, providing EMF great potential advantages over the quasi-static forming process. Firstly, light-weight forming equipment is possible [11]. In EMF process, the inertia effects of the forming tools are remarkable, which can effectively constrain the pulsed forming force, therefore, a light-weight forming equipment can supply sufficient mechanical robust for the system [11]. Secondly, better forming quality may be obtained. Researches [10, 11] indicated that, due to the high strain rate effect, the inertia stability effect, and the high velocity impact with die, EMF can improve formability of some materials, suppress wrinkling, and reduce spring-back. Thirdly, much higher forming flexibility is enabled [10]. In the process, the spatial distribution and temporal evolution of the forming force−Lorentz force−can be flexibly controlled, by altering the structure of the forming coil and the wave shape of the excited electric current for the forming coil, respectively.

The abovementioned potential advantages offer EMF a great prospect for manufacturing large sheet parts. Despite of the potential advantages and the great prospect of EMF, much more efforts still need made to overcome the obstacles of the existing EMF technique, such as the poor performance life of the forming coil and the relative low stored energy of the power source. By this way, these potential advantages can be transformed into concrete benefits. Some existing applications of EMF for relative large sheet forming may refer to [9, 12-14]. To the best knowledge of the authors, two largest sheet parts formed by EMF in publications are with diameters of 640 mm [14] and 780 mm [9], respectively. In reference [9], 36 electromagnetically strikes with relative low energy (about 5.2 kJ), combined with stretch forming process, were proposed to form the sheet metal. While in reference [14], one high energy (about 100 kJ) electromagnetically strike provided by a high strength forming coil was applied to shape the large sheet metal.

In this paper, the proposal that shapes large sheet metal with one high energy electromagnetically strike was adopted due to much higher production rate. Attempts were made to overcome the existing EMF obstacles, and to exploit the potential advantages of EMF. A comprehensive EMF facility with capability to form a 1378 mm sheet metal was fabricated. The feasibility of the facility was experimentally proved.

2. Electromagnetic forming facility

Fig. 1 presents the proposed EMF facility. The facility can form sheet metal with a diameter of 1378 mm. Compared to the forming machines in [1, 2], the proposed facility is very light-weight, and has following dimensions: