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A Study on Flame Forming of Bowl Shaped Surface with Various Spiral Irradiating Schemes

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ABSTRACT In this paper, various strategies of spiral irradiating scheme for the flame forming of a bowl shaped surface are investigated experimentally and numerically. Experimental work is performed using a flame torch integrated with a 2-axis CNC workstation. The ABAQUS implicit solver is used in the numerical simulation. Three different strategies of the spiral irradiating scheme are investigated for the flame forming of a bowl shaped surface. The first strategy is the Simple spiral irradiating scheme, the second is the Rotational spiral irradiating scheme, and the third is the Symmetrical-Rotational spiral irradiating scheme. The results show that using the Symmetrical-Rotational spiral irradiating scheme, a bowl shaped surface with the maximum deformation can be produced, followed by using the Rotational scheme, and the Simple spiral scheme. It is also concluded from the results that the spiral irradiating scheme with Symmetrical-Rotational, Rotational and Simple spiral schemes lead to the maximum symmetries in the produced bowl shaped surface, respectively. All the numerical results are in good agreement with the experimental observations.

KEY WORDS flame forming, bowl shaped surface, spiral irradiating strategy

I. INTRODUCTION

Metal forming with a moving heat source is an economical and one of the best methods in industries. Flame forming is an important process with moving heat source that can be used for bending and spatial forming of plates. In the flame forming process, a plate is irradiated with a flame heat flux. In the heating stage, due to the irradiated heat flux into the plate, plastic strain is induced; and after cooling stage, the plate is formed to the desired shape. Many studies have been performed on the two-dimensional flame forming. However, due to the extreme complexity of the three-dimensional flame forming, little research has been done in this field. Some studies in the field of three-dimensional sheet metal forming are reviewed as follows. In 1994, Ueda et al.[1] developed a new procedure for the bending of plates with flame forming process using the finite element method and strain-based calculation. Their results showed that the proposed method was suitable for the bending of plates using a movable heat source. In 2000, Yu et al.[2] used some algorithms for the development of a curved surface into a flat plate. They also used a strain-based method which was shown to be a powerful procedure. In 2010, Seong et al.[3] proposed a geometrical method and successfully deformed a flat plate into the desired shape using a flame heat. They also obtained the process parameters through their relationship with the geometrical ones. In 2010, Yang et al.[4] investigated the temperature, stress-strain and deformation fields in a three-dimensional laser forming process using the finite element method. In their study, a spherical

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dome was fabricated out of a square sheet using the spider line strategy. Their results showed that in a three-dimensional laser forming process, thermal stress and stress wave were the main factors. In 2013, Shi et al.[5] investigated the effects of path spacing and crossed heating lines on the plastic strain in the bending process of a plate with a laser heat source in a thermo-mechanical coupled finite-element analysis. Their results showed that for parallel heating lines, plastic strain fields produced by adjacent scans did not affect each other when the path spacing was larger than the laser spot diameter, but the plastic strain fields produced by the adjacent scans affected each other when the path spacing was smaller than the laser spot diameter. In 2013, Wang et al.[6] produced a three-dimensional curved steel tube from a straight tube. They presented a bending method based on the geometric curvatures with a scanning path planning decomposed into a two-dimensional model and restructured into a three-dimensional model, sequentially. The results showed that the scanning path planning proposed in their paper was effective and feasible. A few studies have been done in the field of forming a bowl shaped surface with a moving heat source. In 2000, Hennige[7] investigated the laser forming process of a bowl shaped surface using radial and circular heating paths and showed that a bowl shaped surface could be produced successfully with the combination of radial and circular paths. In 2012, Chakraborty et al.[8] produced a bowl shaped surface using radial and circular heating paths. They also investigated the effects of various process parameters, viz., laser spot diameter, laser power and scan speed, on the in-plane and out-of-plane forming of stainless steel circular blanks for various circular and radial scan schemes.

In this work, various strategies of spiral irradiating scheme for the flame forming of a bowl shaped surface are investigated experimentally and numerically. Because the magnitude of deformation per pass in the flame forming of a bowl shaped surface is small, more passes are needed to obtain the bowl shaped surfaces with large deformation in the flame forming process. In this paper three different strategies of spiral irradiating scheme arrangement in the multi-pass flame forming of a bowl shaped surface are proposed and compared. In the first strategy referred as the Simple spiral path in this paper, the spiral irradiating scheme is repeated in its previous position in multi-pass processes. In the second strategy referred as the Rotational spiral path in this paper, the position of spiral irradiating scheme is changed about 90° in each pass relative to the previous one. In the third strategy referred as the Symmetrical-Rotational spiral path in this paper, the position of spiral irradiating scheme is changed about 180° in the second pass relative to the first, and then changed about 90° in the third pass relative to the second, and finally changed about 180° in the fourth pass relative to the third. It should be noted that during the flame forming process of thick plates, temperature gradient mechanism is the dominant mechanism[3], in which sheet thickness under irradiating path increases and necking in the plate does not occur. However, in the flame forming of plates of large dimensions, two important features (i.e. amount of deformation and symmetry of flame formed part) should be checked for each produced part. Therefore, in this paper, the amount of deformation and symmetry of the produced parts are investigated for various spiral irradiating schemes. The results show that using the Symmetrical-Rotational spiral irradiating scheme, a bowl shaped surface with the maximum deformation can be produced, followed by using the Rotational scheme, and the Simple spiral scheme. It is also concluded from the results that the spiral irradiating scheme with Symmetrical-Rotational, Rotational and Simple spiral paths lead to maximum symmetry in the produced bowl shaped surface, respectively. All the numerical results are in good agreement with the experimental observations.

II. Experimental Work

All the specimens are circular blanks cut from as-received mild steel. The dimension of the circular blanks is 280 mm (Diameter) × 12 mm (Thickness). Experiments are performed using an oxy-acetylene flame torch integrated with a 2-axis CNC workstation. Figure 1 shows the experiment setup of flame forming and the obtained bowl shaped surface with spiral path. The heating conditions of flame forming process for the production of bowl shaped surface are presented in Table 1.

As mentioned above, in this paper three different strategies of spiral irradiating scheme are used and compared for the production of bowl shaped surface with large deformation, which are the Simple spiral path, Rotational spiral path and Symmetrical-Rotational spiral path explained in the previous section. The schematic view of Simple spiral path is shown in Fig.2. In this strategy, the spiral irradiating scheme is repeated in the second, third and fourth passes.