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Experimental investigation of laser forming of a saddle shape with spiral irradiating scheme

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ABSTRACT

In this work, spiral irradiating scheme is proposed and investigated experimentally for laser forming of a saddle shape. It is proved by experimental results that this new irradiating scheme is a suitable and powerful method for production of saddle shapes. In addition, the effects of various process parameters such as pitch of spiral path, number of spiral paths, in-to-out spiral path and reversely out-to-in spiral path on the obtained saddle shape are investigated. The results show with decreasing the pitch of spiral path, due to increase in the induced heat flux into the plate, deformations in other words curvatures of obtained saddle shape are considerably increased. Also it is shown that curvatures associated with out-to-in spiral path are larger than curvatures of in-to-out spiral path due to change in geometrical constraints. It is seen from results that with increasing the number of irradiation passes, curvatures of obtained saddle shape are increased considerably.

1. Introduction

A laser forming process has been introduced in the last decades and applied in sheet metal forming industries. Compared with mechanical bending, no hard tooling or die or external force is used in the laser forming process. Laser beam induces thermal stresses into the surface of a work-piece and creates plastic strains. Considerable amount of research has been carried out on two-dimensional laser forming. However, in order to advance the process further to industrial applications, it is necessary to study and digest 3D laser forming. 3D laser forming studies have recently been investigated and few research works have been reported in this field due to extreme complexities. In 1997, Shimizu [1] applied generic algorithms to a dome shape sheet to determine required amount of heat, assuming laser scanning paths are known. In 1998, Jang and Moon [2] developed an algorithm to determine heating lines based on the principal curvatures of deflection difference surface that represents the shape difference between a desirable shape and an intermittent shape fabricated from the original planar shape. Candidate heating regions are selected by grouping the points where principal curvatures are larger. In 2000, Yu et al. [3] presented optimal algorithms for flattening of double curved surfaces while the strain from the surface to its planar development is minimized. The development process was modeled by in-plane strain (stretching) from the curved surface to its planar development. In 2001, Edwardson et al. [4] in an experimental study investigated the rules for the positioning and sequencing of the irradiation lines required for the controlled 3D-laser forming of a symmetrical saddle shape from rectangular sheet material. Their results showed that the problem of 3D laser forming is extremely complex. In 2004, Cheng and Yao [5] proposed a method to present laser scanning paths and heating conditions for dome and saddle shapes from thin sheet metal. In their method, scanning paths are designed based on the concept of in-plane strain, principal minimal strain and temperature gradient mechanism laser forming. Heating condition is determined by a lumped method. In determination of laser scanning paths and heating conditions, however, this method only considered the in-plane component of the total strain and thus may incur larger errors for thicker plates. In 2005, Liu and Yao [6] proposed an FEM-based 3D laser forming process design method, which extends the applicability of Cheng's method to relatively thicker plates by considering bending strains in addition to in-plane strains. In 2009, Kim and Na [7] proposed a new method for 3D laser forming of sheet metals. Their method used geometrical information rather than a complicated stress-strain analysis. Using this method, they showed that total calculation time is reduced considerably while provided enhanced accuracy. In this work, spiral irradiating scheme is proposed and investigated experimentally for laser forming of a saddle shape. To the author's knowledge production

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of a double curvature part with a saddle shape and using a spiral path has not been reported. It is proved by experimental results that this new irradiating scheme is a suitable and powerful method for production of saddle shapes. In addition, the effects of various process parameters such as pitch of spiral path, number of spiral paths, in-to-out spiral path and reversely out-to-in spiral path on the obtained saddle shape are investigated.

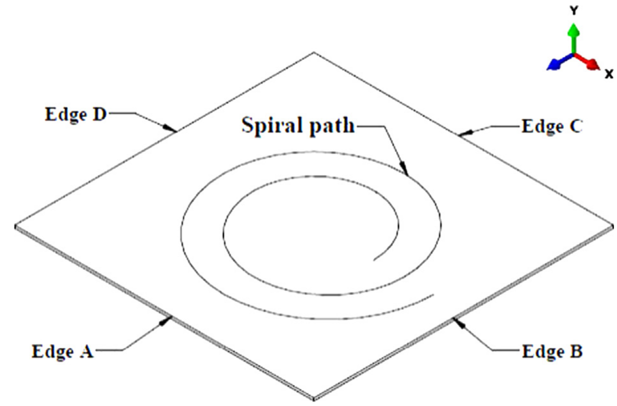
2. Experimental work

In the experiments, the samples are made from mild steel with 100 mm (length) × 100 mm (width) × 0.85 mm (thickness). Laser forming experiments are carried out with a continuous CO_2 laser with the maximum power of 150 W. The samples are first cleaned with acetone and then coated with graphite in order to improve the heat absorptivity of the irradiated surface. In Fig. 1, experimental set up for laser forming of a saddle shape and formed specimens are shown. Also, in Fig. 2, a square plate and schematic view of a spiral path are shown.

3. Results and discussion

In the experiments it was observed that a spiral irradiating path on a square or rectangular plate would always yield a saddle shape. In the forming of a saddle shape, curvatures values on the edges and also symmetry of final shape are important parameters that should be checked. In Figs. 3 and 4, *Y*-displacements of the free edges A, B, C and D for obtained saddle shape with the above mentioned spiral irradiating scheme are shown. *Y*-displacements have been measured with a coordinate measuring machine (name and model of the CMM: Easson ENC-565). The accuracy of measurements for this machine is 0.5 μm.

It is seen from Figs. 3 and 4 that curvatures of the obtained saddle shape are noticeably large. Hence it was concluded that



Spiral path information	
First circle radius	20 mm
Spiral pitch	10 mm

Fig. 2. Schematic view of a square plate and its spiral path information.

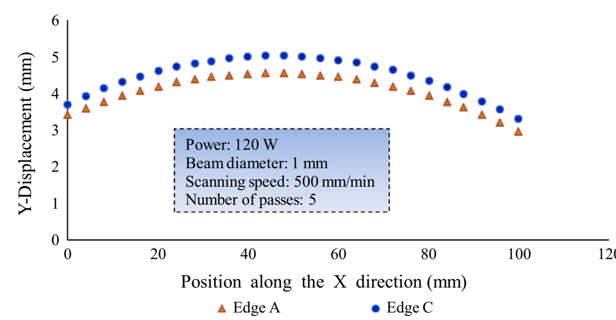


Fig. 3. Experimental results of *Y*-displacements of the free edges A and C.

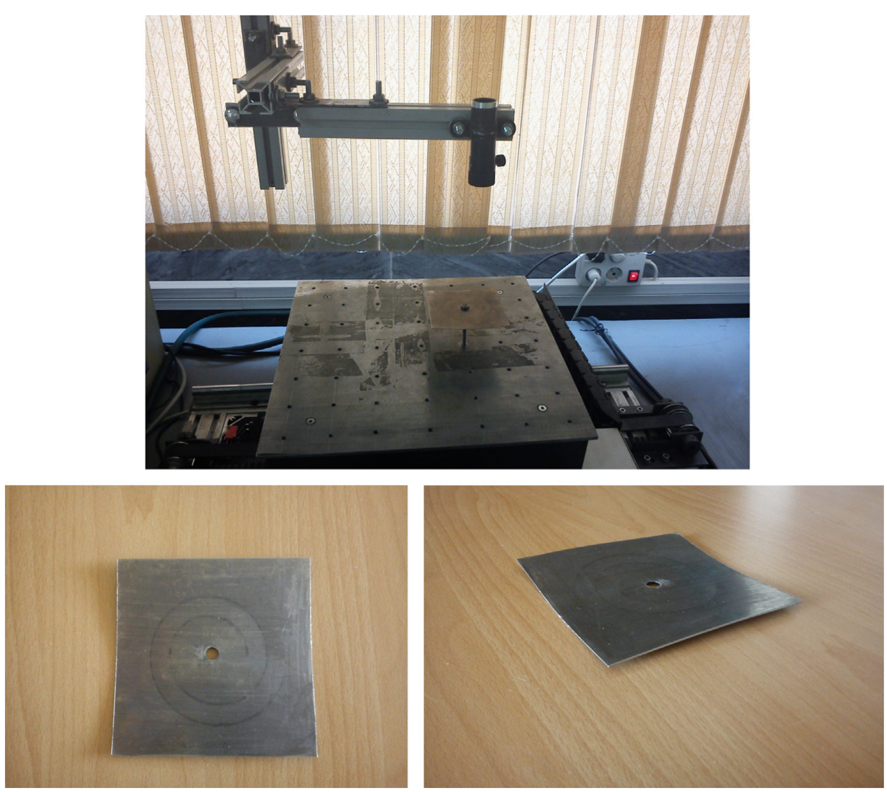


Fig. 1. Experimental set up for laser forming of a saddle shape and formed specimens.