Journal of Materials Processing Technology 227 (2016) 169–177

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Study on reducing edge effects by using assistant force in laser forming

Yongjun Shi*, Chen Zhang, Guidong Sun, Chuanxiu Li

College of Mechanical & Electronic Engineering, China University of Petroleum, Qingdao, Shandong 266580, China

ARTICLE INFO

Article history:
Received 12 November 2014
Received in revised form 1 July 2015
Accepted 17 August 2015
Available online 21 August 2015

Keywords:
Laser forming
Edge effect
Heating method
Assistant force
Metal plate

ABSTRACT

The laser forming process, in which a bending deformation of a metal plate is produced by nonuniform thermal stress coming from nonlinear laser-heating cycles, is a promising technology for the rapid production of metallic shaping components. In laser forming, except for the desirable bending deformation, the bending angle varies along the laser-heating line. This undesirable deformation, or edge effect, exists because the forming process is asymmetrical, which leads to the forming accuracy failing to reach the design requirement. To reduce the edge effect, a method with various assistant forces is proposed and the effects of these different forces on forming accuracy have been studied. The results show that the forming accuracy can be improved under the action of two unequal concentrated forces. The relative variation of the value of the bending angle decreases by about 80% compared with that of the pure laser forming when the proper external forces are chosen. The laser process parameters also play an important role in the bending angle variations under constant geometry, material, and assistant forces. The final shapes of a forming part may be controlled to a desirable accuracy by selecting the proper assistant forces and process parameters.

1. Introduction

The laser forming technique has its origins in oxyacetylene flame line heating for ship hull construction (Scully, 1987). Although the energy input of the two heat sources is different, the processes share similarities in temperature distribution, forming mechanism, path planning, etc. In laser forming, a metal plate is plastically deformed by nonuniform thermal stresses introduced into the local surface during the laser scanning and cooling process. This technology offers promise for the short production of metallic shaping components (Sistaninia et al., 2009). Its advantages are that 1. It requires no external forces and 2. Many hard and brittle materials can be processed. Its disadvantage lies in the fact that forming accuracy cannot usually reach the design requirements because of the elimination of stamping dies and presses. In the laser forming process, the bending angle was found to vary along the heating line, which was known as the edge effect (Magee et al., 1997). The influence of the edge effect on the service performance of a forming part must be taken into account in high-precision manufacturing.

There are mainly three kinds of forming mechanisms suggested to describe the deformation behavior in laser forming (Vollertson, 1994a): temperature gradient mechanism (TGM), buckling mechanism (BM), and upsetting mechanism (UM). The type of forming mechanism activated mainly depends on the process parameters for a given workpiece. Bao and Yao (2001) performed a numerical investigation to reveal the edge effect mechanism in BM-dominated processes. Two causes for the bending variation were found, one being that the temperature of the exit point is much higher than that of the entrance point and the other being the curved bending edge. Magee et al. (1997) analyzed the effects of laser process parameters and material properties on the edge effect. To reduce the edge effect, a method was proposed in which the heating velocity along the scanning line was varied. The results showed that the varying velocity can result in a sizable reduction of bending angle variation. Shi et al. (2013) discussed the edge effect under conditions of different laser process parameters. Their results indicated that the forming accuracy can be improved by increasing the laser beam power. Shi et al. (2011) showed that the geometry sizes of the plate have an important influence on the bending angle variation. The relative variation in the bending angle greatly decreases with an increase of the length, whereas it increases as the width or thickness increases. Jha et al. (2008) analyzed the edge effect in laser forming of AISI 304 stainless steel, demon-

* Corresponding author.
E-mail address: syjgl@126.com (Y. Shi).

http://dx.doi.org/10.1016/j.jmatprotec.2015.08.018

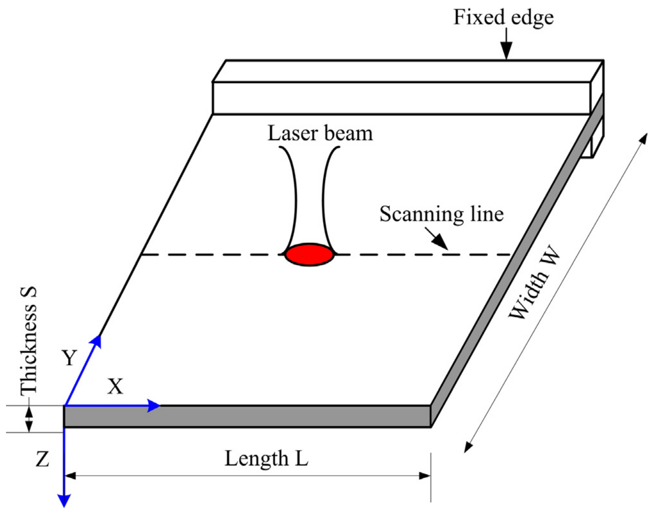

Fig. 1. Schematic of a conventional heating process with a laser beam.

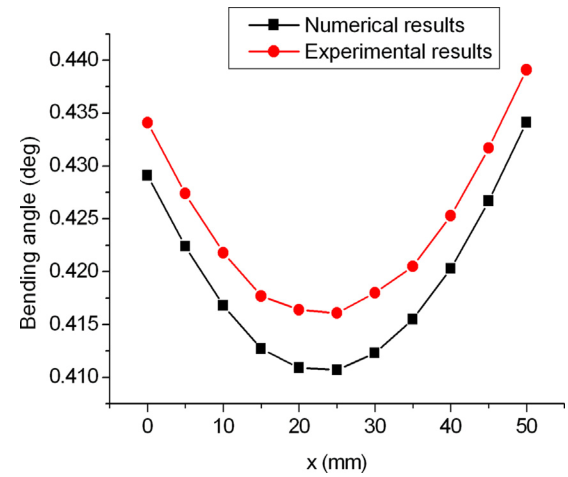

Fig. 2. Comparison of experimental and numerical results (for a plate size of $50 \times 50 \times 2\,mm^3$).

strating that the proper laser parameters can assist in reducing the irregularity of the bending angle, with a combination of two of three optimal parameters or higher number of passes making it possible to control for the edge effect. Shen et al. (2010) proposed six varying velocity scanning schemes used to decrease the edge effect. The experimental results showed that this method of combining acceleration and deceleration can reduce the edge effect, and relative bending angle in an example from the literature varies from 16% for constant-speed heating to 5.6% by using this method. Hu et al. (2013) improved an analytical model presented by other researchers to predict the edge effect and proposed a new method by changing the constraint condition. The experimental results showed that the variation of the bending angle using the new method is smaller than that using the conventional method. Cheng et al. (2005) proposed an analytical model of the bending angle to predict the edge effect by modeling a moving-strip heat source over a finite-size plate, in which the pre-bending effect had been considered. The model-predicted trends showed good agreement with the experimental and simulation results. Furthermore, passive water cooling can reduce the difference between the entrance and exit temperatures of a laser-scanned sheet, which is helpful for decreasing the edge effect (Lambiase et al., 2013). It follows that laser process parameters, geometry size, and material properties are the important controlling parameters for reducing the edge effect.

Despite the improvement made in previous research, the forming accuracy still needs to be raised further in industrial applications. In this work, a method in which different external loads are applied is presented to reduce the edge effect of a plate in laser forming. The effects of the magnitude of the force on forming accuracy have been examined to obtain the optimum value of the loads. Finally, the relationship between the laser process parameters and the edge effect is analyzed to better understand the causes of the inaccuracy produced.

2. Numerical simulations and experimental verification

A schematic of a conventional laser forming process, including a Cartesian coordinate system (*X*–*Z*), is shown in Fig. 1. Generally, one end of the plate is clamped and the other is kept free. Cooling of the heated plate is mainly accomplished through forced water cooling or forced natural air cooling. Natural air cooling has little influence on the material property compared with forced water cooling. Forced water cooling is usually used for multiple laser scans because it can reduce production time. Natural air cooling is employed in this study.

In the following analysis, because bending deformations toward the laser beam are needed for most industrial applications, cases in which the temperature gradient mechanism is dominant are researched by selecting proper parameters. Because laser forming is a thermal-mechanical coupling problem, it is very difficult to obtain an analytical solution. Vollertsen (1994b) proposed a two-layer model based on the temperature-gradient mechanism. Shen et al. (2006) presented an analytical model to estimate the bending angle based on a history-dependent incremental stress–strain relationship by considering plastic deformation. Lambiase (2012) developed an analytical model adopting a two-layer model to evaluate the bending angle based on the evaluation of thermal strain, which is suitable for TGM conditions and BM-to-TGM transition conditions. However, in none of these models is the effect of the plate edge on the bending angle considered. A three-dimensional finite-element model has been established to simulate the heating and deforming process (Shi et al., 2011). The nonlinear finite-element software ANSYS is used in the numerical simulations of the laser forming. The structure analysis can be decoupled from the thermal analysis because the heat generated by plastic deformation

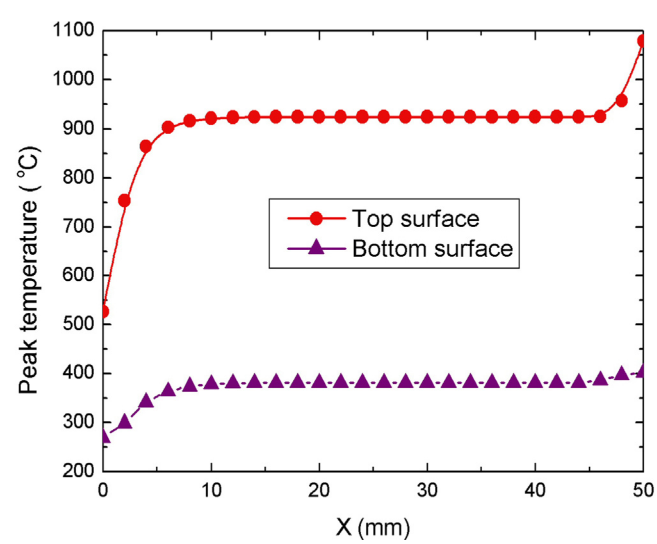

Fig. 3. Variation of peak temperature reached on the top and bottom surfaces along the heating path.