Parametric Study and Optimization of Pulsed Laser Thermal Micro-Forming of Thin Sheets

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ABSTRACT

This article presents the investigations on deformation behavior in precision forming of thin sheet metal by laser pulses using finite element analysis. The temperature and deformation fields were estimated and analyzed in pulsed laser micro-forming of AISI 304 stainless steel sheet of rectangular and circular shape considering the effects of different process parameters such as laser power, spot diameter and pulse on time. Response surface models based on finite element simulation results were developed to study the effects of the process parameters on deformations for the rectangular and circular workpieces. The amount of deformation was increased with the increase in laser power and pulse on time, and it was decreased with the increase in spot diameter. The effects of pulse frequency and sample size on deformations were also explained. Experiments were conducted on pulsed laser micro-forming of stainless-steel sheet to validate the finite element results. The results of finite element simulations were in good agreement with the experimental results.

KEYWORDS


1. INTRODUCTION

Laser thermal micro-forming is a non-contact technique to deform a metal sheet at micro-scale using the controlled distribution of thermal stresses induced by a defocused laser beam. A precise deformation or adjustment of thin sheet metal components by continuous and pulsed laser irradiations has potential applications in micro-manufacturing, micro-machines and devices, actuators, hard disks, microelectronics components and others. Miniaturization, geometric complexity and dimensional accuracy required for fabrication of micro devices placed a huge challenge for assembly and adjustment works. The conventional mechanical methods for precision forming and adjustment are limited in giving the desired accuracy due to the spring-back and hard-tooling requirements. Moreover, fabrication of micro-parts or devices is highly sensitive to mechanical forces and particularly to the impact loads. Laser thermal micro-forming is advantageous compared to mechanical one with the limitation thermal effects for the heat sensitive materials. Therefore thermal-structural analysis in
laser thermal micro-forming, parametric study and optimization of process parameters for fabrication and adjustments works is essential for its effective applications. The research work on laser thermal micro-forming or micro-adjustments carried out in the past are discussed below.

Numerical simulations of pulsed laser bending and forming thin sheet metals were carried by different researchers considering single and multiple laser pulses under different processing conditions. Qi et al. (2010) carried out experimental investigations and finite element analysis to study the effects of parameters on the laser adjustment of a rod. Laser thermal adjustments of actuators made of stainless steel and aluminum alloy were studied by investigators (Shen & Yao, 2011; Shen et al., 2012; Shen at al., 2015). Actuators with different cut-out geometries was investigated by Shen et al., 2012 considering the effects of different process parameters, and it was concluded that the effects of cut-out geometries must be considered in optimizing the process parameters. Experimental study on laser thermal adjustment of sheet metal micro-parts was carried out by Griffith et al. (2014) using pulsed modes of laser irradiations with different process parameters. It was observed that ablation of the laser irradiated sheet surface for short duration pulse was less compared to the long duration pulse heating. It was also found that type and amount of deformation was significantly influenced by both sample geometry and material properties. Fokkersma et al. (2016) proposed an algorithm for alignment of micro tube through laser micro forming using statistical analysis of the previous deformation data. The proposed algorithm was validated by micro tube laser bending experiments and found to predict alignment with good accuracy. Laser forming of shaped surfaces were investigated using finite element analysis experiments and other methods by different researchers (Jovic et al., 2017; Maji et al., 2018). Deformation of the samples with the different process parameters was studied and the most significant variables were identified to affect bending and thickening in laser forming of shaped surfaces. The deformation mechanism and process parameters of thermal forming mechanism are discussed as the following.

In pulsed laser micro-forming (PLμF), thin sheet metal parts are heated in a discontinuous manner. The deformation in pulsed laser thermal micro-forming can be explained by considering the effect of the temperature gradient and residual stress point mechanism. The process parameters in pulsed laser forming are laser power, spot diameter, pulse frequency and duty cycle. The pulse on time depends on the combination of laser pulse frequency and duty cycle. As the pulse frequency increased at a constant duty cycle, the pulse on-time decreased and consequently, the energy per pulse decreased. The thermal forming mechanisms consists of the local thermal expansion due to laser heating which is hindered by surrounding cold material, and therefore produces thermal stress which results in local plastic deformation when it exceeds the temperature dependent flow stress of the material as shown in Figure 1.

The nature and magnitude of deformation in PLμF depends on the material properties, sheet geometry and process parameters. Laser power, duration of laser irradiation and size of plastic zone decide the amount of deformation. In case of multiple laser pulses irradiation at constant laser power and duty cycle, the pulse-on time and time between two pulses got reduced with the increase in frequency. If the time interval between the two pulses becomes more than the characteristic thermal diffusion time, then the heating at a given point will remain unaffected by the previous pulses.

Figure 1. Deformation mechanism in pulsed laser heating
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