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Procedia Manufacturing 2 (2015) 397 – 401

Procedia MANUFACTURING

2nd International Materials, Industrial, and Manufacturing Engineering Conference, MIMEC2015, 4-6 February 2015, Bali Indonesia

Finite element analysis of micro scale laser bending of a steel sheet metal subjected to short pulse shock wave

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Abstract

Short pulse laser micro-bending is intended as a non-thermal forming process utilizing the shock wave induced by laser irradiation to bend of micro scale components. In this paper, the bending behavior of a micro scale AISI 304 sheet was investigated during short pulse laser bending by the finite element method. A dynamic explicit analysis relied on incident wave for loading process was employed to obtain the effect of laser power and laser spot position on the stress and strain distribution and maximum bending displacement. Results show effect of laser power on bending process is more considerable in comparison with laser spot position.

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Selection and Peer-review under responsibility of the Scientific Committee of MIMEC2015

Keywords: Sheet metal forming; Laser micro-scale bending; bending displacement; Finite element analysis

1. Introduction

Due to the dramatically increasing demand for micro products in the area such as medical, automotive, optical and chemical industry, appropriate processes for machining of related components have become very important issues [1]. Laser technology has been qualified for micro-technology because of its high lateral precision by minimized focusability to a few microns, low heat input and high flexibility [2]. One of the well-used applications of laser manufacturing process is micro scale laser forming such as bulging, bending and etc [3, 4].

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Selection and Peer-review under responsibility of the Scientific Committee of MIMEC2015
doi:10.1016/j.promfg.2015.07.070

In general terms, micro scale laser bending is a high strain rate micro forming method which is implemented by a short or long laser pulse in the rate of nanoseconds. Short laser shock bending is a non-thermal process by utilizing the shock wave produced by laser irradiation [5]. It has the benefits of laser thermal forming such as non-contact, tool-free and high efficiency and accuracy. But its non-thermal operation makes it possible to maintain material properties or improve them by inducing compressive stress over the target surface, which is desirable since it is important in industry for shaped metal parts to resist cracks from corrosion and fatigue [6]. This transient forming operation is hard to record by in-situ measurements. In order to better understand the forming mechanism of micro scale laser bending and the effects of involved parameters on the trend of shock process, numerical study can be useful [7, 8]. Laser bending of square cross-section tubes was investigated by Krauss via finite element model [9]. Also, laser tube bending of circular cross section employing FEM and analytical techniques was studied by Hao and Li [10, 11]. A linear relationship between bending angle and laser power and a non-linear relationship between bending angle and number of laser passes were realized in their research. Finite element simulation of laser tube bending to investigate the effect of scanning schemes on bending angle, distortions and stress distribution was carried out by Safdar and et.al [12]. Based on the results presented in their paper, it was evident that scanning schemes significantly influence laser tube bending parameters. Jun Hu and et.al [13] presented a finite element model using multi-layered shell elements for laser bending. They generated a simple, robust and accurate modelling method of laser bending by comparing the efficiency and accuracy of solid, solid-shell, and multi-layered shell models.

This paper presents a finite element study of the effects of laser spot position on maximum bending displacement and stress distribution in laser sheet bending of AISI 304. A commercial finite element package, ABAQUS, has been employed to simulate the process, taking into account the short pulse laser and mechanical properties.

2. Principle of the numerical procedure

A high energy impact wave produces plastic deformation in metals. In this paper short pulse laser bending was studied as an application of high energy impact waves. A series of 3D numerical simulations were performed using the ABAQUS explicit commercial software. To simulation, a dynamic analysis based on incident wave was defined. The process of loading is specified via various distances between laser spot position and the top surface of specimens. The diameter of laser beam is adjusted to 0.1mm. Other details of simulation are as follows.

2.1. Assumptions, geometry and material

The workpiece materials are isotropic; the laser acts in a short pulse wave mode; no melting occurs in the laser bending process and no external forces are applied to sheet metal. Johnson-Cook constitutive equation [14] is used to predict the mechanical behavior of specimens. The sheet metal is considered flat and free of residual stress. The Johnson-Cook equation is as follows.

$$\sigma_{eq} = (A + B\varepsilon^{n})\left(1 + C\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right)\left(1 - \left(\frac{T - T_r}{T_m - T_r}\right)^{m}\right) \tag{1}$$

where σ_{eq} is the equivalent flow stress, ε is the equivalent plastic strain, $\dot{\varepsilon}$ is the equivalent plastic strain rate normalized by a reference strain rate $\dot{\varepsilon}_0$, T_m is the melting temperature of the material and T_r is the room temperature, while A, B, C, m and n are material constants. The Johnson-Cook material constants and properties are listed in Table 1 [15]. The material for specimens is AISI 304 in the form of 1000 x 1000 μm square cross-section sheet metal with the thickness of 50 μm.

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