



Light press of sheet metal edge for reducing residual stress generated by laser cutting considering mechanical properties and intensity of residual stress



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ABSTRACT

Laser cutting has started to be used as an effective method for cutting out blanks from rolled sheet metals because of its high flexibility for cutting lines and high productivity. However, residual stresses, which are generated by laser cutting, have been the greatest obstacle for the popularization of laser cutting. One of the problems is the warp which appears in the sheet metal after being subjected to bending processes after laser cutting. The authors present a light press method for reducing residual stress generated by laser cutting. The method is to give a light press on the sheet metal edge and to reduce tensile residual stress generated near the laser cutting surface. In particular, this present paper especially focuses upon optimization of working conditions depending on mechanical properties of the blank and the effect of the heat affected zone in laser cutting. Experiments of U-bending after applying light press were conducted for usability of this method. The FEM analyses were carried out in order to investigate proper working conditions depending on various mechanical properties. As a result, the optimum press pressure of the light press method for various mechanical properties was found out for reducing residual stress which caused by laser cutting, by taking warp after U-bending as an evaluation parameter. The relationship between the optimum pressure and the proof stress was quantitatively and specifically clarified for several sets of mechanical properties. It was also found that the influence of heat-affected-zone area and intensity of residual stress by laser cutting on the optimum press pressure was small.

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1. Introduction

Sheet metal bending is one of the most concise and common methods for production of frames, chassis and other various products. Although bending is a simple process, there are many problems in production. For example, spring-back should be predicted or levelled for manufacturing products with high precision, and it is difficult because of kinematic hardening or the existence of free surface. Some research works have been conducted for overcoming the spring-back problem. For example, Imai et al. (2007) developed the system of high-accuracy V-bending. This system can evaluate the material properties in a 1st step bending at less angle than the target one and determine the final punch stroke for the target angle by predicting the spring-back after release. In addition, Shape defects of sheet metal bending were researched by several authors.

Tozawa and Munenori (1998) found the mechanism of warp generation at web in U-shape bending of aluminum alloy sheets. Tozawa explained the elastic recovery and spring-back of flange cause the web warp because of volumetric constancy. Kazama et al. (2004) developed the analysis method of warp deformation and the mechanism of camber generation at the edge and web in sheet metal bending. Huang and Chen (2003) reported the finite-element analysis of camber process of V-bending. It can predict the precise camber after bending. Residual stress is another problem. Although the sheet metal might be flat and straight if the residual stress is well balanced, some warp or curvature might occur if the balance is disturbed by machining or metal forming including bending.

Laser cutting has started to be used as an effective method for cutting out blanks from rolled sheet metals because of its high flexibility for cutting lines and high productivity. However, the residual stresses which are generated by rapid temperature change have been the greatest obstacle for the popularization of laser cutting. Some researches were carried out to examine the effect of laser cutting. Ito et al. (2009) discovered the generation of residual stress

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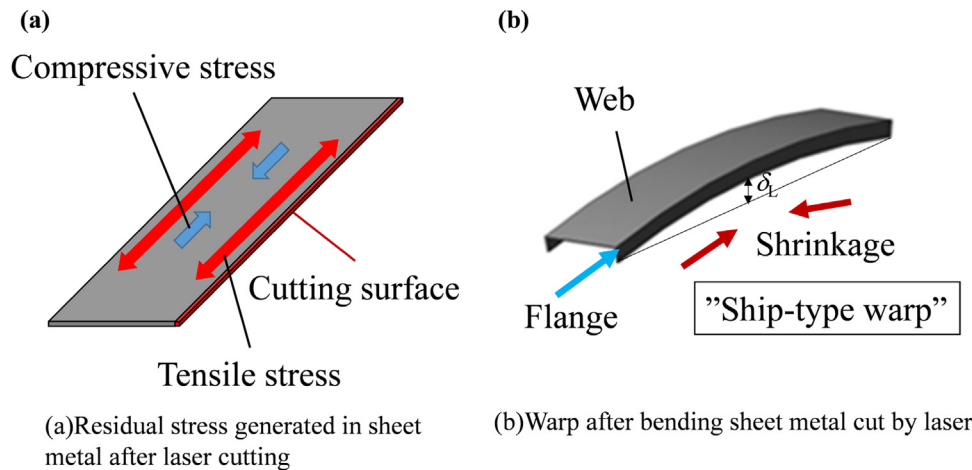


Fig. 1. Mechanism of warp after bending sheet metals which was cut by laser. (a) Residual stress generated in sheet metal after laser cutting, (b) warp after bending sheet metal cut by laser.

and hardening effect of thin sheet metal by laser cutting. Arif et al. (2009) investigate residual stress of thick sheet metal and tailored blanks after laser cutting by FEM and X-ray diffraction technique. In thick sheet metals, Yilbas et al. (2009) discovered high temperature gradient in the region of the laser heat source. One of the problems is the warp which appears in the sheet metal after being subjected to bending processes following the laser cutting. Jin et al. (2010) researched the warp generated by residual stress and the mechanism of warp generation. It is important to reduce the residual stress for suppression of warp after the bending process. Leveller processing or annealing are known as effective methods to reduce residual stresses. Aoki et al. (2012) proposed another reduction method of residual stress using vibrations with different frequencies. Tensile residual stress is reduced largely when ultrasonic vibration and low-frequency vibration are used. However, the equipment is large-scale and expensive. Therefore, simple and appropriate methods are required for the reduction of the residual stresses which were generated by laser cutting.

This paper presents a light press method for reducing residual stress generated by laser cutting. The method is to give light press on the sheet metal edge and to reduce tensile residual stress generated near the laser-cut surface. In particular, the present study focuses upon the optimization of the light press condition depending on mechanical properties of the sheet metal and the intensity of residual stress generated by laser cutting. Experiments were firstly conducted for verifying the effectiveness of the proposed method for low carbon steel and stainless steel.

2. Proposed method

When sheet metal is blanked by laser cutting, residual tensile stress near the laser cut surface is generated. The generated compressive stress and residual tensile stresses are well balanced in the sheet metal as shown in Fig. 1(a). When the balance of the residual stress in the flange surface is disturbed by bending, the “ship-type” warp occurs as shown in Fig. 1(b). Therefore, it is essential to reduce or control the residual stress occurring near the laser cutting surface for attaining the dimensional accuracy after bending the sheet metal. Tension leveller and stretch levelling are known as methods of reducing the residual stress. However, as the equipment is expensive, there are problems in the cost and productivity. Hence, simple methods are demanded for the industrial use.

The proposed method is schematically shown in Fig. 2. The light press method is concise and its productivity is very high. In the proposed method, the sheet metal edge, which has been cut

by laser, should be pressed by a slight amount in the thickness direction.

The mechanism of reducing the residual stress is explained by the relationship between the shrinkage by laser cutting and the longitudinal expansion by light press method at the edge of the sheet metal. The cut edge of the sheet metal shrinks at the end of laser cutting process due to rapid cooling. On the other hand, the rest part does not shrink and constraints the shrinkage of the edge, resulting in the generation of tensile stress at the edge as shown in Fig. 2(a).

The slight thickness reduction elongates the sheet metal in width direction due to volumetric constancy, leading to relaxation of the tensile stress caused by laser cutting as shown in Fig. 2(b). This method is utilizing plastic deformation in the thickness direction. Experiments and FEM analysis were carried out to determine the proper conditions of press.

3. Experiment

3.1. Experiment procedure

The sheet metal, which had been sectioned out into a rectangle shape by the laser, was subjected to the proposed method of light press. Then, the sheet metal was bent in the U-bending manner for the evaluation of the effect of the light press for levelling of the residual stress as shown in Fig. 1(b). The warp height δ_L was used as the index for the intensity of the residual stress because the warp height should increase with increase of the tensile stress along the laser-cut edge. Low carbon steel SPCC (JIS) and stainless steel SUS304 (JIS) were used in the experiment, the stress-strain diagrams of which are shown in Fig. 3. The Stress-strain diagram was approximated by Swift's law

$$\sigma = F(\varepsilon^p + \varepsilon_0)^n \quad (1)$$

where σ is true stress, ε^p is plastic strain, F is hardening coefficient, n is hardening exponent, and ε_0 is offset of yield strain. Mechanical properties of these materials are shown in Table 1. The sheet metal edge was pressed by the punch for the whole length in the longitudinal direction and for 2 mm in the width direction, because the residual tensile stress is generated within the range of 2 mm from the laser-cut surface. The size of the laser-cut sheet metal was 400 mm in the longitudinal direction and 65 mm in the width direction. The flange length was 10 mm in the U-bending direction.

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