Invited paper

DIE AND MOLD-LESS FORMING OF SHEET MATERIALS-CURVED SURFACE FORMING BY LASER IRRADIATION

Hideki Aoyama[1] and Satoshi Kishida[2]

[1, 2]Department of System Design Engineering, Keio University, Yokohama, Japan,
Tel: 81-45-566-1722, 81-45-566-1720, e-mail: haoyama@sd.keio.ac.jp, kerecyo@ma.sd.keio.ac.jp

Received Date: May 8, 2012

Abstract

Laser forming is expected to be able to form a desired shape out of sheet metal or sheet plastic without the use of a die or mold. Laser forming plastically deforms the material by generating local heat stresses, and enables low cost rapid prototype or small lot production, since it eliminates the need for dies and molds. Although there are many studies on laser forming, there are relatively few studies on forming curved surfaces. The objective of this paper is to develop a method for forming curved surfaces out of sheet material utilizing laser irradiation. To achieve this objective, a method to determine the scanning paths and the scanning condition for making curved surfaces by laser irradiation is proposed. The scanning paths are determined as the maximum and minimum curvature lines, and the scanning condition, which is a function of the scanning speed, is derived from basic experiment data. Since the maximum and minimum curvature lines are orthogonal, they do not influence each other during forming.

Keywords: Curved surface, Die, Laser forming, Mold, Sheet material

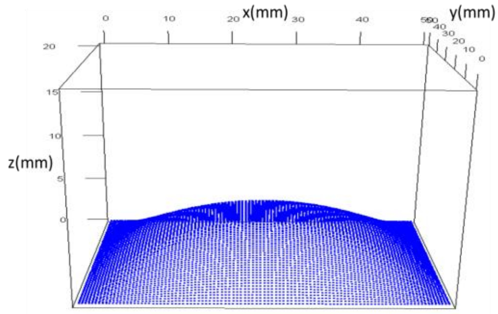
Introduction

The forming of sheet metal/plastic is generally done by press working or injection molding. Press working and injection molding are highly effective for mass production, but they are an inappropriate method for prototype and small-quantity production due to their high costs and the long amount of time it takes to produce dies and molds.

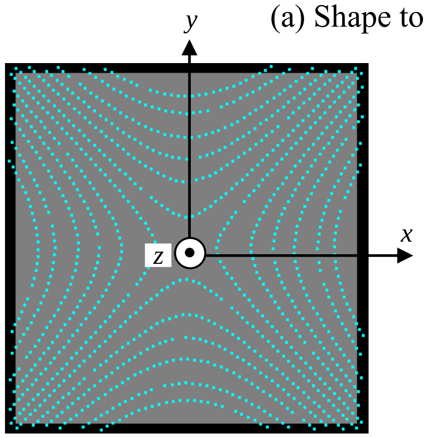
Laser forming is a technology that forms sheet metal/plastic by irradiating a laser beam on a sheet surface to produce local heat stresses, which cause plastic deformation. Since it does not use dies or molds, it enables one to rapidly make prototypes and to decrease the cost and time for small-quantity production. There have been several works [1-11] on laser forming thus far. However, the objective of almost all of these works has been to elucidate the phenomenon of laser forming through experiments and through the FEM analysis of simple bending. There are few studies on curved surface forming and practical system development.

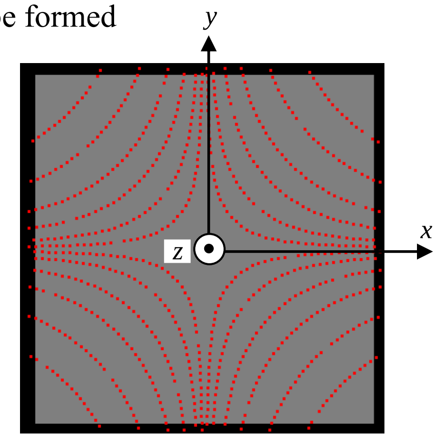
In this paper, in an effort to establish practical technology for making curved surfaces by laser forming, the following items are executed.

(1) Development of a method to determine scanning paths to form a curved shape of sheet material by laser irradiation,
(2) Development of a method to determine the irradiation conditions,
(3) Development of a basic system to irradiate a laser beam on the determined scanning paths with the determined irradiation conditions, and
(4) Verification of the effectiveness of the proposed method and the developed system.



(a) Shape to be formed





(b) Minimum curvature lines (c) Maximum curvature lines

Figure 1. Scanning paths

Method to Determine Scanning Paths

The scanning paths to form curved shapes by laser irradiation were determined as maximum and minimum curvature lines. Since these lines are orthogonal to each other, the deformations caused by laser beam irradiation on maximum curvature lines are not influenced by the deformations caused on minimum curvature lines. To form a curved shape, a laser beam was first scanned on minimum curvature lines, and then secondly scanned on maximum curvature lines [12]. Figures 1 (b) and (c) show the examples of a required shape's maximum and minimum curvature lines respectively, as shown in Figure 1 (a).

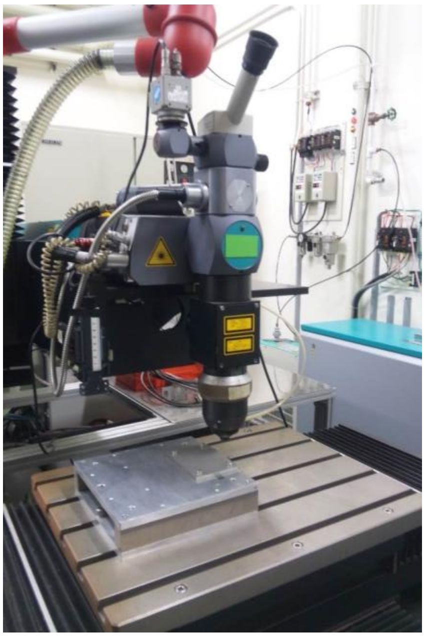


Figure 2. YAG laser machine

Method to Determine Irradiation Conditions

The irradiation conditions of the laser beam were determined from basic experiment results. Figure 2 shows the YAG pulsed laser Machine Hitachi Construction Machinery Co., Ltd./ LU-100, Lee Laser/80tTQ) used in the experiments. Stainless steel (SUS304) specimens with a thickness of 0.1 mm, width of 10 mm, and length of 30 mm were utilized in the experiments. The specimens were fixed and a pulsed laser beam was vertically irradiated on the specimen surface as shown in Figure 3.

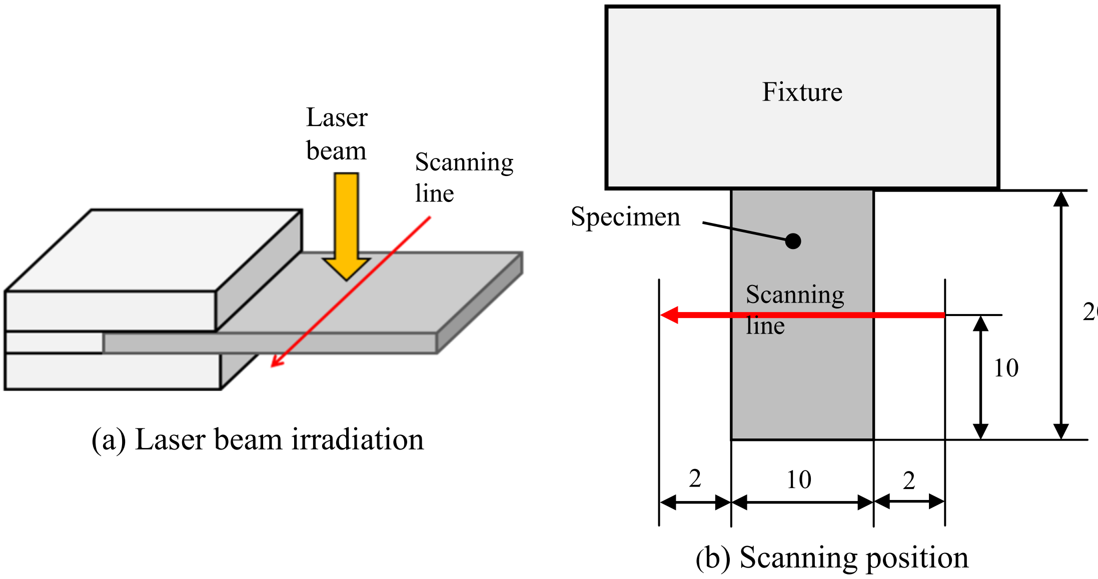


Figure 3. Laser beam scanning in basic experiments

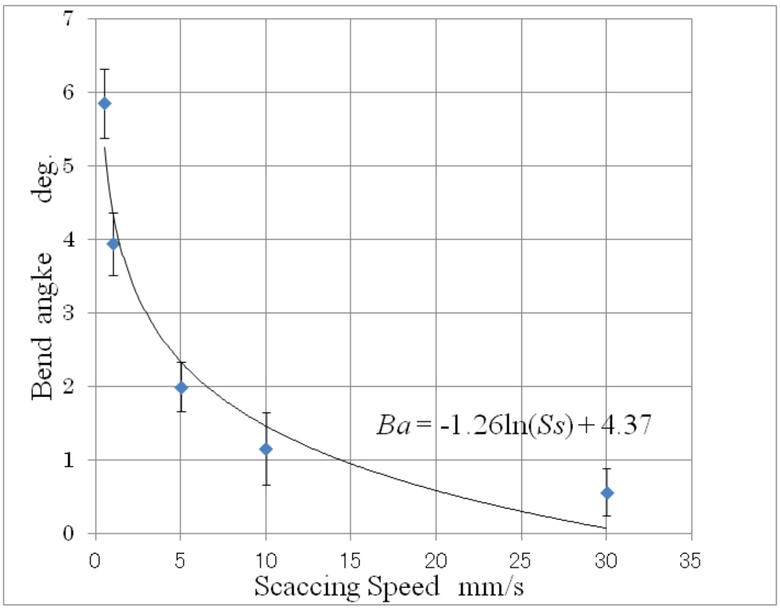
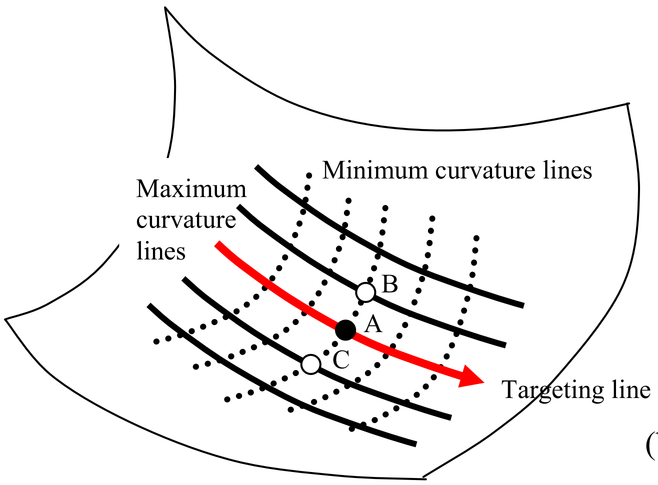


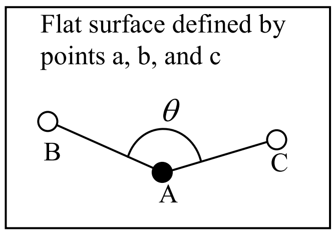
Figure 4. Basic experiment results

The irradiation conditions of a pulsed laser beam are the laser power, pulse width, pulse frequency, laser spot diameter (which varies with the defocal length), scanning speed, and number of scans. In the experiments, the scanning speed was varied as the only forming parameter, while all other conditions (pulse width of 0.1 ms, pulse frequency of 100Hz, laser spot diameter of 0.1 mm when the defocal length is 2 mm, and number of scans of 1) were fixed. In the basic experiments, the scanning speed was set to 0.5, 1.0, 5.0, 10.0, and 30.0 mm/s. A forming test of each scanning speed was carried out three times. Figure 4 shows the relationship between the scanning speed and the bending angle. As a result, the scanning speed *Ss* (mm/s) is determined by Equation (1) according to the required bending angle *Ba* (deg.).

$$Ss = \frac{\exp(4.37 - Ba)}{1.26} \qquad (1)$$



(a) Maximum and minimum curvature lines



(b) Required bending angle at point A

Figure 5. Derivation of required bend angle

Method to Derive Required Bending Angle

As mentioned above, the scanning speed at each irradiation point can be determined by the required bending angle according to equation (1). The required bending angle is derived as follows.

The scanning paths are determined as maximum and minimum curvature lines. When a laser is irradiated at point A on the currently scanned maximum curvature line as shown in Figure 5 (a), the required bend angle at point A is derived as the angle θ between lines A-B and A-C as shown in Figure 5 (b). Points B and C are on a minimum curvature line which passes through point A, and are on maximum curvature lines which run adjacent to the currently scanned line. The angle θ is easily calculated by the cosine formula because the coordinates of points A, B, and C are known.

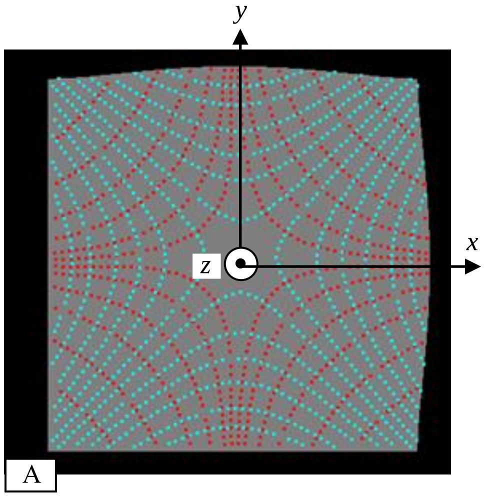


Figure 6. Expansion of lines on flat surface

Transformation of Maximum and Minimum Lines on to Flat Surface

Initially, the material to be formed has a flat surface. Therefore, the scanning paths generated from a required shape must be transformed onto a flat surface to obtain the required scanning paths on the initial material. Figure 6 shows the lines to be irradiated, which were obtained by transforming the maximum and minimum curvature lines shown in Figure 1 (b) and (c) onto a flat surface with point A as the cardinal point. In other words, points A is the fixed point. As shown in Figure 1 (b) and (c), the required shape is square when viewed on the *x*-*y* plane. As a result, the original material shape is not square when viewed on the *x*-*y* plane as shown in Figure 6.

Compensation of Laser Beam Head Position

The laser spot diameter, which is one of the irradiation conditions, depends on the defocal length determined by the distance between the laser beam head and the point of irradiation. Through forming though, the initially flat material is gradually deformed by laser irradiation and this length is changed.

Therefore, the position of the laser beam head must be determined by not only the scanning paths, but also by the deformed material shape. In the proposed method, the deformation shape is estimated at each point of irradiation and the position of the laser beam head is accordingly compensated.

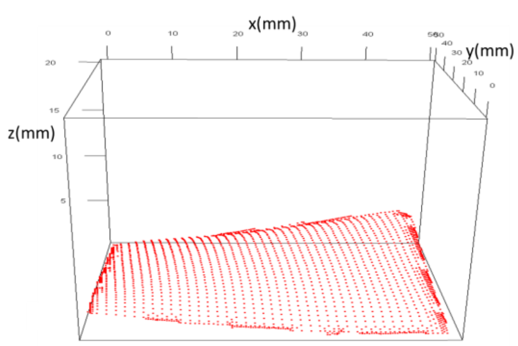


Figure 7. Formed curved surface shape

Test to Form Curved Surfaces

A test to confirm the feasibility of forming curved surfaces by laser irradiation was conducted. The desired shape is shown in Figure 1 (a). The laser beam head position was controlled according to the scanning lines on the *x-y* plane shown in Figure 6 and the z-position was also controlled to keep the defocal length constant by compensating for the z-position errors caused by the deformation of the material. The scanning speed *Ss* at each point was determined by equation (1), as a function of the required bending angle *Ba* at each point. Other than the scanning speed, all other scanning conditions were fixed, that is, the pulse width was 0.1ms, pulse frequency was 100Hz, laser spot diameter was 0.1mm (defocal length was 2 mm), and the number of scans was 1.

Figure 7 shows the formed shape. In the results, the formed shape has large errors when compared with the required shape. However, the feasibility of curved surface forming was confirmed by the experiment.

Conclusions

In this paper, basic technology to form a curved shape out of sheet material by laser irradiation was developed. The results described in this paper are summarized as follows.

(1) Scanning paths to make a curved shape by laser irradiation are determined as maximum and minimum curvature lines.
(2) The deformations generated by laser irradiation on maximum and minimum curvature lines do not influence each other because maximum and minimum curvature lines are orthogonal to each other.
(3) A method to determine the irradiation conditions for a pulsed laser beam has been developed.
(4) Laser power, pulse width, pulse frequency, laser spot diameter (defocal length), and number of scans were fixed in the determination of irradiation conditions, and only the scanning speed was controlled according to the deformed angle at each irradiated point.
(5) The scanning paths on a flat plane of sheet material were obtained by transforming the maximum and minimum curvature lines of a required shape.
(6) The laser beam head position was also controlled according to the estimated deformed shape at each irradiation point.
(7) A basic system to irradiate a laser beam on the scanning paths with the irradiation conditions has been developed.
(8) The feasibility of forming curved surfaces by laser irradiation was verified.

References

[1] M. Otsu, and H. Miura, “Three-dimensional forming of sheet metal,” *Journal of Japan Laser Processing Society*, Vol.10, No. 3, pp. 238-242, 2003.

[2] T. Ueda, K. Yamada, S. Oikawa, and A. Hosokawa, “Basic study on laser forming,” *Journal of the Japan Society of Precision Engineering*, Vol. 67, No. 2, pp. 300-305, 2001.

[3] M. Saeki, A. Sakakibara, and K. Hosokawa, “Simulation of laser forming-1st report, effect of plate thickness and beam diameter on bending direction,” *Journal of the Japan Society of Precision Engineering*, Vol. 74, No. 2, pp. 160-165, 2008.

[4] Y. Namba, and T. Katayama, “Three dimensional thermal elastic-plastic analysis of laser forming process,” *Journal of the Japan Society of Precision Engineering*, Vol. 65, No. 9, pp. 1330-1334, 1999.

[5] M. Osawa, T. Hatayama, T. Okubo, and Y. Uchiyama, *Fundamental Study on Micro-Forming by Laser Beam*, Annual Report Research Institute for Technology, Tokyo Denki University, No. 20, pp. 113-118, 2001.
[6] M. Osawa, Y. Itoh, and H. Sato, *Plastic Forming of Micro Parts by Laser Beam*, Annual Report Research Institute for Technology, Tokyo Denki University, No. 23, pp. 95-100, 2004.
[7] M. Osawa, H. Ichikawa, and H. Sato, *Plastic Deformation of Thin Metal Sheet by Laser Beam*, Annual Report Research Institute for Technology, Tokyo Denki University, No. 25, pp. 95-100, 2006.
[8] T. Miyazaki, M. Saito, T. Tokunaga, T. Misu, and S. Yoshioka, "Diode laser forming of thin metal plate using pre-bending effect," *Journal of the Japan Society of Precision Engineering*, Vol. 68, No. 5, pp. 700-704, 2002.
[9] T. Misu, Y. Sano, T. Miyazaki, S. Yoshioka, T. Tokunaga, and Y. Tanaka, "Laser bending of thin metal plate : Effect of workpiece size and shape on bending occurred due to buckling mode," *Journal of the Japan Society of Precision Engineering*, Vol. 71, No. 12, pp. 1536-1540, 2005.
[10] Y. Okamoto, Y. Uno, K. Ohta, T. Shibata, S. Kubota, and Y. Namba, "Study on precision laser forming of plastic with YAG laser," *Journal of the Japan Society of Precision Engineering*, Vol. 66, No. 6, pp. 891-895, 2000.
[11] Y. Uno, Y. Okamoto, T. Shibata, and M. Ohkubo, "Study on laser forming of plastic by YAG laser : Effect of specimen thickness on deformation characteristics", *Journal of the Japan Society of Precision Engineering*, Vol. 68, No. 3, pp. 466-471, 2002.
[12] K. Matsuo, K. Matsuoka, S. Hatase, and K. Iwasaki, "New plate development method by using curvature line and its application," *Journal of Marine Science and Technology*, Vol. 11, No. 1, pp. 285-286, 2005.