Characteristic of energy input for laser forming sheet metal

Liqun Li (李俐群), Yanbin Chen (陈彦宾), and Xiaosong Feng (封小松)

State Key Laboratory of Advanced Welding Production and Technology, Harbin Institute of Technology, Harbin 150001

Received March 18, 2003

Laser forming is a process in which laser-induced thermal deformation is used to form sheet metal without a hard forming tool or external forces. The energy input of laser beam is the key factor for the temperature and stress distribution of sheet metal. The purpose of this work is to investigate the influence of energy input condition on heat input and deformation angle for two-dimension laser forming. Variations in heat input resulting from material deformation was calculated and discussed in this paper at first. Furthermore, in laser forming under the condition of constant laser energy input, the effects of energy input mode on deformation angle and temperature field were investigated.

OCIS codes: 350.3390, 140.3390.

Laser forming has become a viable process for the shaping of metallic components. This flexible forming technique easily met the various requirements of consumers. It is especially suitable for low-volume production or rapid prototyping of sheet metal, as well as for adjusting and aligning sheet metal components[1−3].

During laser forming process, the change of material properties, geometrical shape and dissipation condition will affect the deformation rate of sheet metal. Therefore, for the higher forming accuracy, monitoring temperature, shape dimensions and adjusting laser energy on real-time are necessary, the laser forming process is described schematically in Fig. 1. Generally, people pay more attention to investigating the shaping dimension with different laser power, but ignore the variation of heat input resulting from sheet deformation[4−7]. Constant laser energy does not mean that the heat input is constant. This investigation aims to complement the considerable amount of work already completed on two-dimension laser forming, offering an insight into the heat input behavior in the forming process and the influence rule of different heating methods on the temperature field and deformation angle.

The defocusing beam is usually used for irradiating sheet metal in laser forming process for obtaining the large deformation. The deformation of material leads to the change of irradiation area on the workpiece surface and defocusing amount, which influences the heat input

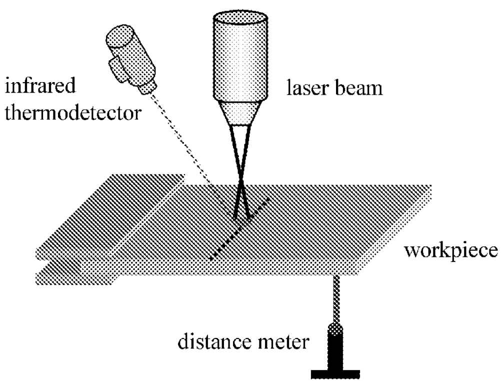

Fig. 1. Setup of laser forming sheet metal.

condition of sheet surface. The simple single-axle bend is achieved when laser beam muti-pass scanning the top surface along a straight line. As can be seen in Fig. 2, the spot shape varies from circle to ellipse because of the bending deformation of sheet metal, according to the relationship between defocusing amount and spot radius, the heat input at random point of workpiece surface can be expressed by the following equations.

On the arc surface of the bending plate, the heat input at random point can be written as

$$I(x,y) = \frac{2AP}{\pi R'^2} \exp\left[-2\frac{r^2 \sin^2(y/r) + x^2}{R'^2}\right] \cos(y/r), \quad (1)$$

where $I(x,y)$ is heat input at random point (x,y) of workpiece surface, A is the absorption coefficient, $R' = R/\Delta f \cdot [\Delta f - r + r\cos(y/r)]$, P is laser power, Δf is defocusing amount, R is the spot radius on the flat sheet, and r is the arc radius.

The heat input on the flat surface of the bending plate can be calculated as

$$I(x,y) = \frac{2AP}{\pi R''^2} \exp\left[-2\frac{(r\sin\alpha + y\cos\alpha - r\alpha\cos\alpha)^2 + x^2}{R''^2}\right] \cos\alpha, \quad (2)$$

where $R'' = x^2 + [r\sin\alpha + (y - r\alpha)\cos\alpha]^2$, α is the deformation angle.

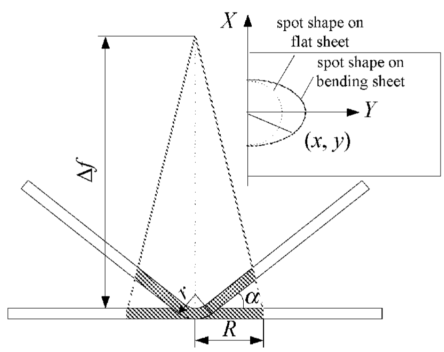

Fig. 2. Influence of deformation angle on heat input.

When the workpiece is a thin sheet, the arc radius r is small, which is relative to the bending angle of the plate, the nature of the material, the thickness of the workpiece and the radius of the laser beam, etc. In order to simplify the calculation, the bending angle should be approximated to wedge angle. So, the heat input at the random point of the workpiece surface can be written as

$$I(x,y) = \frac{2AP}{\pi R^2(1 - y\sin\alpha/\Delta f)^2} \exp\left[\frac{-2(y^2\cos^2\alpha + x^2)}{R^2(1 - y\sin\alpha/\Delta f)^2}\right]\cos\alpha. \quad (3)$$

Figure 3 shows the distribution of heat input at different deformation angle calculated by Eq. (1), the 2-mm-thick pure sheet was irradiated by YAG laser whose focusing length is 200 mm and laser power is 1500 W. As can be seen in Fig. 3, the heat input on the per unit area decreases with increasing deformation angle. It can also be noted that the heat input is changed, which is because of the unequal defocusing amount at different location in the irradiation region. Figure 4 shows the temperature distribution on the direction cross the scanning line, which is calculated by finite elementary method (FEM). From the temperature distribution, it can be seen that the peak temperature does not locate on the center of the laser beam when sheet metal occurs bend. As a result, the thermal stress around the scanning line reduced, which is an unfavorable effect for sheet bending.

In order to integral analyze the energy effect in laser forming process, the conceptions of line energy and area energy were introduced in this paper. Line energy is defined as $LE = P/V$, which represents the laser energy input per unit length along the scanning path. Area energy $AE = P/Vd$, which represents the average energy applied to unit area along the scanning path, although the intensity of the laser beam normally has a Gaussian distribution. Here, P is the laser power, V is scanning speed, and d is the beam diameter.

As we know, increasing line energy means the increase of laser energy input, which gives advantage to improving material deformation. Whether we may infer that the constant line energy input will induce the same deformation degree in laser forming process? The answers can be found in Fig. 5, it shows the deformation angle and

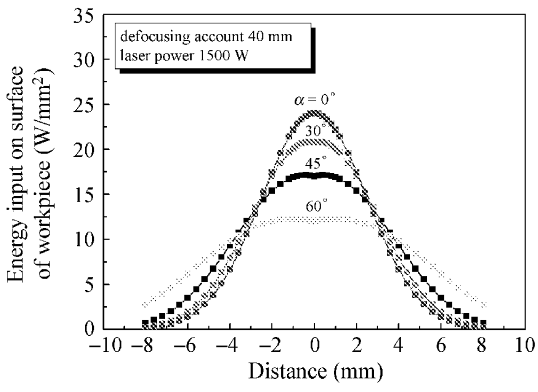

Fig. 3. Heat input at different deformation angle in laser forming process.

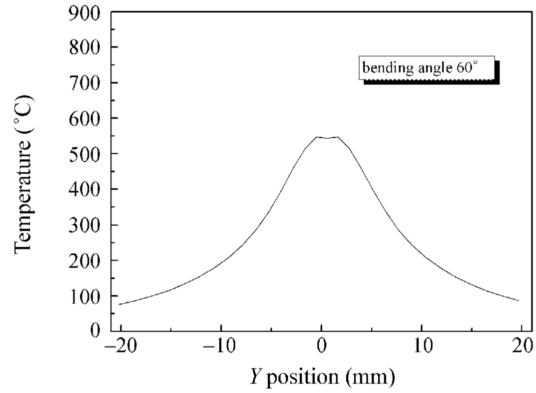

Fig. 4. Temperature distribution of bent sheet.

temperature of sheet metal at different scanning speed under the constant liner energy. It can be seen that at the lower scanning speed, deformation angle increases with increasing scanning speed, while at the higher scanning speed, the deformation angle approximately keeps constant (Fig. 5(a)).

We have studied the laser forming under condition of constant line energy, that is, the ratio between laser power and scanning speed is kept constant. When laser power and scanning speed is varied, the heat dissipation rate and strain rate will change and result in deformation. Heat has less time to conduct at higher speed, as a result, the temperature and temperature gradient are higher than those at lower speed, as seen from Fig. 5(b), this is advantage to the deformation of sheet metal. Moreover, the higher temperature at the higher speed has

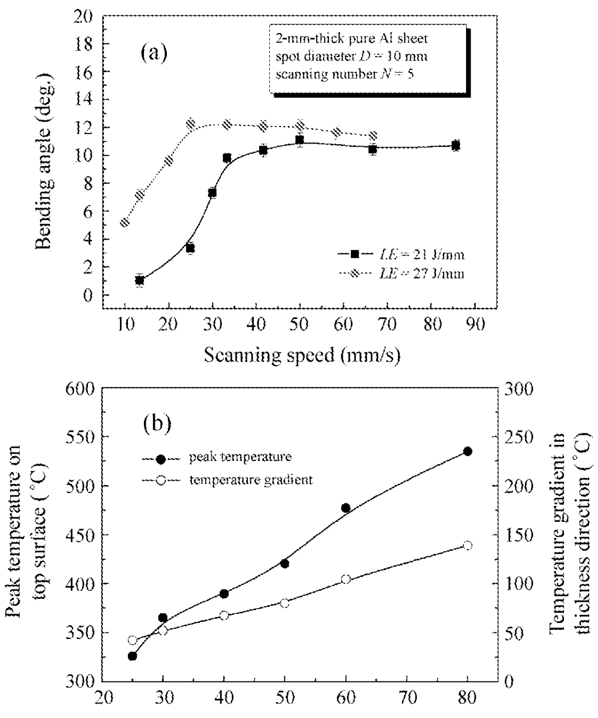

Fig. 5. Bend characteristic of sheet metal under the condition of constant line energy. (a) Deformation angle at different scanning speed; (b) peak temperature and temperature gradient of material at different scanning speed.

a conflictingeffect on the material flow stress. Flow stress decreases as temperature increases but increases with strain rate. The increased temperature makes the effect of strain rate on flow stress more pronounced, the net effect of the higher speed on flow stress therefore cannot be readily predicted. The experimental results demonstrate that the integrated influence of heat dissipation time and strain rate makes the bend deformation of sheet metal approximately keep constant at higher speed.

Figure 6 shows the deformation characteristic of sheet metal under the condition of constant area energy. The graphs indicate an increase in deformation angle with the increase in beam diameter. Although the temperature of material increases with the increase of beam diameter, the temperature gradient in thickness direction decreases. It can be concluded that, in laser forming under the constant area energy, the increase of deformation angle at large spot diameter has been attribute to the great deal of material accumulation which owes to enlarging the area of plastic region, rather than raising the temperature gradient in thickness direction.

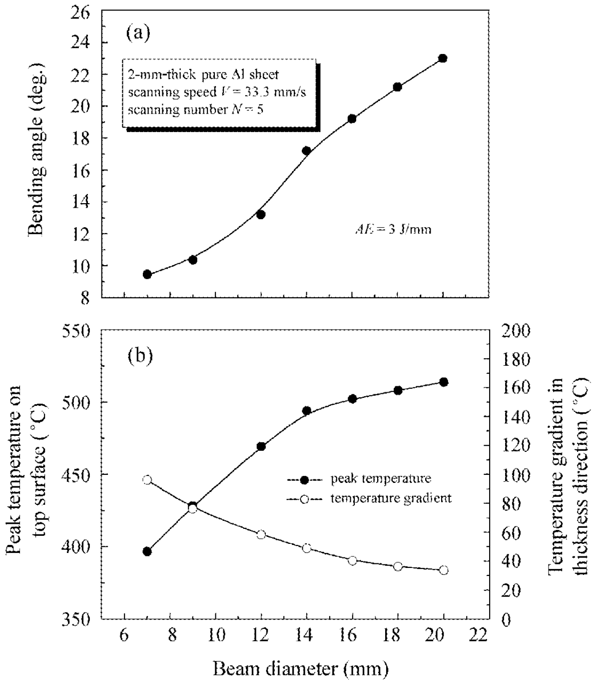

Fig. 6. Bend characteristic of sheet metal under the condition of constant area energy. (a) Deformation angle at different scanning speed; (b) peak temperature and temperature gradient of material at different scanning speed.

In conclusion, the deformation of sheet metal induced by laser beam changes the heat input condition. Predicting the bending angle in laser consecutive scanning process, the influence of deformation dimensions on heat input must be considered. In laser forming under the condition of constant line energy, the larger deformation angle can be obtained at higher scanning speed. Under the condition of constant area energy, the increase of heating area has no help to improve the temperature gradient, but increases the amount of plastic deformation material, which is the main reason of the deformation angle increase.

L. Li's email address is liliqun@hit.edu.cn.

References

1. F. Vollertsen, Laser and Photoelectron **1,** 34 (1996).
2. M. Geiger, Annals of the CIRP **43,** 563 (1994).
3. C. L. Yau, K. C. Chan, and W. B. Lee, in *Proceedings of ICALEO 1996, Section E* 124 (1996).
4. S. Holzer, H. Arnet, and M. Geiger, in *Laser Assisted Net Shape Engineering Proceedings of the LANE'94* 379 (1994).
5. H. Arnet and F. Vollertsen, J. Engineering Manufacture **209,** 433 (1995).
6. M. Geiger and F. Vollertsen, Annals of the CIRP **42,** 301 (1993).
7. C. S. Zhong and J. T. Han, *The Calculation for Plastic Deformation Stress of Metal* (in Chinese) (Metallurgical Industry Press, Beijing, 1992).