INFLUENCE OF TEMPERATURE AND PROCESS PARAMETERS ON BENDING ANGLE IN LASER FORMING

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Abstract Laser-forming is sheet metal bending processing caused by the thermal stresses in the sheet irradiated by a laser beam. Therefore final bending angle of the irradiated sheet depends on the temperature distribution of the sheet. In this study, a thin stainless steel is bended by the irradiation of CO_2 laser. Then both temperatures at irradiated and opposite surfaces are measured using the infrared radiation pyrometer with an optical fiber. And influences of the temperature, thickness of sheet and diameter of laser beam on final bending angle for laser-forming are experimentally investigated. Experimental results show a correlation between the temperature measured and the bending angle achieved. The bending angle linearly increases with an increase of the irradiated surface temperature. In the constant irradiated surface temperature, the increase of diameter of laser beam and the decrease of thickness of material enlarge the bending angle.

Key words laser forming, plastic forming, infrared pyrometer

1 INTRODUCTION

Laser forming is plastic forming using thermal stress induced by laser irradiation. The process has high flexibility required for small-lot-production such as rapid prototyping[1], and it also meets the production of large-scaled components like ship bodies[2], since the expensive molds or dies are not needed in the process. Furthermore, the process can be applied to the adjustment and alignment of small parts inside intricate mechanisms[3][4], because the laser beam can be easily transmitted inward with optical components or glass fibers.

In the laser forming, the achieved shape and bending angle of work material depend on the thermal stress. The stress is determined by various factors, such as the laser irradiating conditions, the restriction of thermal expansion and the changes in material properties depending on the temperature. Therefore, it is difficult to control the deformation of materials. Many researchers have made attempts to introduce valid theoretical models[5][6] which predict the achieved shape of work materials.

Experimental results of these investigations indicate that the deformation of work materials has strong dependence on the temperature at the irradiated area. The temperature has not been measured precisely, because of the difficulty in measuring of the rapid temperature change at the small area. Thus, in a number of studies, the temperature is analytically obtained and the final deformed shape is predicted by theoretical models which require huge calculations like the elastic-plastic finite element methods.

In the present work, the influence of temperature on the deformation of work material is investigated in more detail through the laser bending experiments. The temperature at irradiated surface and at opposite surface of the stainless steel sheet are measured using two sets of the two-color pyrometer with an optical fiber, as the sheet is bent under various laser irradiating conditions. The relation between these conditions and the temperature is clarified and the dependence of the bending angle on the temperature is examined.

2 EXPERIMENTAL METHOD

For the experiments, 1.8kW CO_2 laser is used. Fig.1 shows experimental setup for the laser forming as well as for measuring the temperature of work material. One edge of a thin metal sheet with thickness *h* is clamped on x-y stage and the other edge is free. Both surface of the material are finished by a shot blasting with alumina grains to increase its absorptivity for the laser. The stage moves in y-direction at constant feed rate *V* and the material is scanned by laser beam. Then the temperature of work material is measured by the two-color pyrometer using optical fiber that fixed on steady platform. One fiber aims the center of laser spot on irradiated surface and the other aims the point just below the laser spot on opposite surface, and thermal radiation from heated zone is accepted by the fibers and transmitted to the detectors consisting of InAs device and InSb device. Measured temperature is obtained by taking ratio of the output signals from these two devices

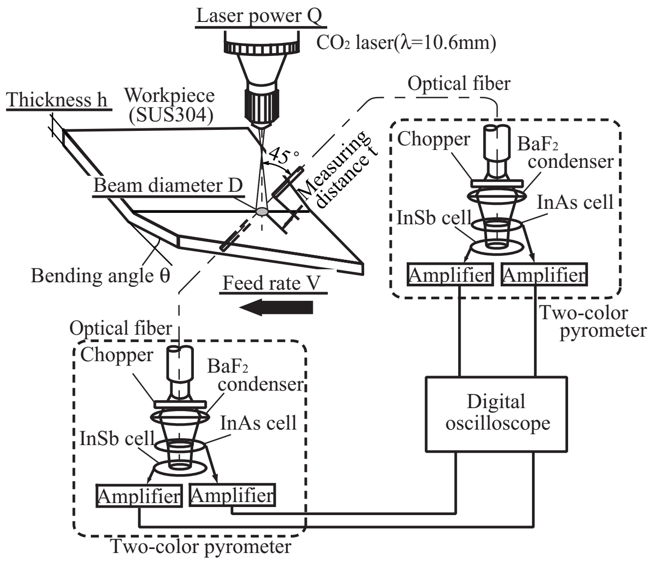

Fig. 1 Experimental set-up

Table 1 Experimental conditions

Workpiece	Material		SUS304
	Dimensions	mm	20×50
	Thickness h	mm	0.3-5
	Blasting grain		WA#320
Forming conditions	Laser power Q	W	
	Beam diameter D	mm	1.42-3.42
	Feed rate V	mm/s	2.5, 5, 10
Measuring condition	Measuring distance t	mm	4,8

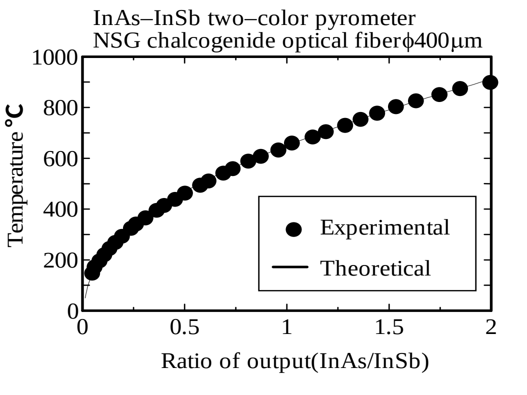

Fig. 2 Calibration curve of two-color pyrometer

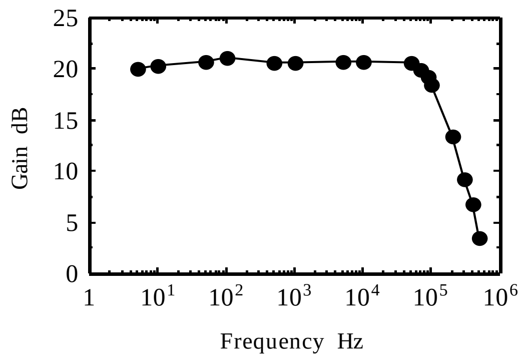

Fig. 3 Frequency characteristics of two-color pyrometer

Fig. 2 shows the calibration curve of the pyrometer, which is obtained experimentally by sighting on the sample heated to constant temperature electrically. The theoretical result indicated by solid line coincides well with the experimental results indicated by circles. As can been seen, temperature higher than 150°C can be measured by the pyrometer. Fig. 3 shows the frequency characteristics of the pyrometers that are crucially important. It has a flat response to about 100kHz which is sufficient for this experiment[7]. But the mechanical choppers are employed as shown in Fig.1 to measure the temperature which does not significantly fluctuate during steady bending process, becouse the gain of pyrometer decreases in low frequency.

3 EXPERIMENTAL RESULTS

3.1 Influence of laser power and feed rate on bending angle

Fig. 4 shows the relation between the laser power *Q* and the measured temperature. Both of the temperatures at irradiated surface *Ts* and that at opposite surface *Tb* increase with the increase of laser power *Q* and the temperature difference between the both surfaces *ΔT* increases with the increase of laser power *Q*.

Fig. 5 shows the influence of laser power *Q* on the bending angle *θ* and on the irradiated surface temperature *Ts*. The bending angle and the irradiated surface temperature increase linearly with the increase of the laser power *Q*. That is because higher temperature at the irradiated surface induces more thermal stress.

Fig. 6 shows the influence of feed rate *V* on the bending angle *θ* and on the irradiated surface temperature *Ts*. The bending angle and the irradiated surface temperature decrease linearly with an increase of the feed rate *V*.

Fig. 7 shows the relation between the irradiated surface temperature and the bending angle in the

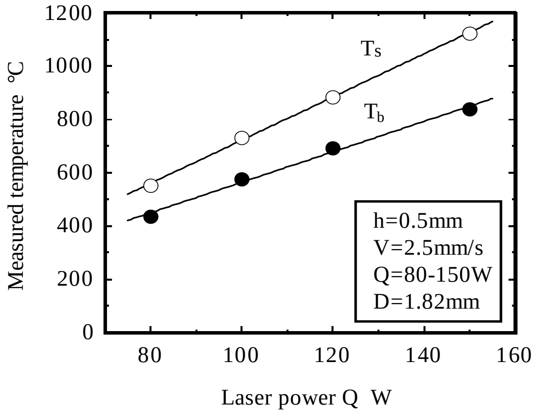

Fig. 4 Relation between Laser power and measured temperature

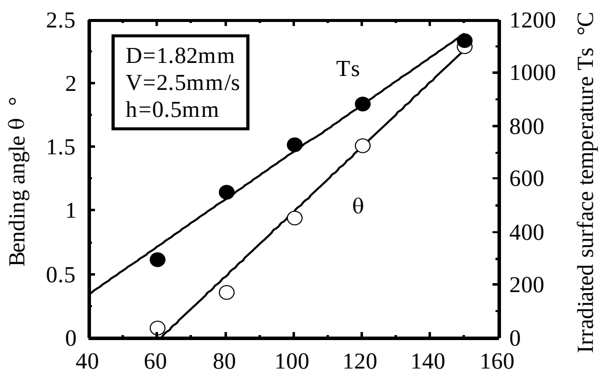

Fig. 5 Influence of laser power on bending angle and temperature

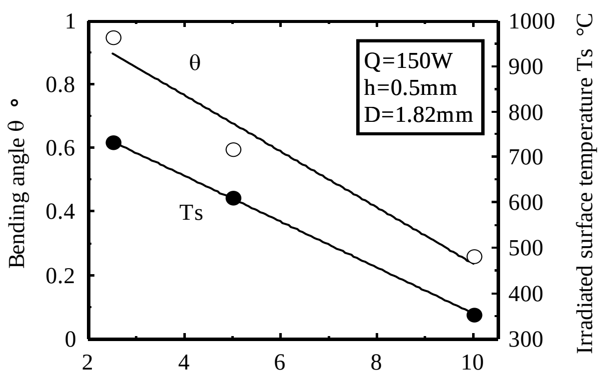

Fig. 6 Influence of feed rate on bending angle and temperature

various conditions of the laser power *Q* and the feed rate *V*. It is found that the bending angle increases linearly with an increase of the irradiated surface temperature. Thus the bending angle can be predicted with the irradiated surface temperature in the various conditions of laser power *Q* and feed rate *V*. And the influence of the laser power and the feed rate on the bending angle can be explained by the measurement of the irradiated surface temperature.

3.2 Influence of thickness of material on bending angle

Fig. 8 shows the influence of the thickness of material on the bending angle and the irradiated surface temperature. The bending angle and the irradiated surface temperature decrease with an increase of the thickness of material *h*. Especially, the bending angle decreases sharply, because of

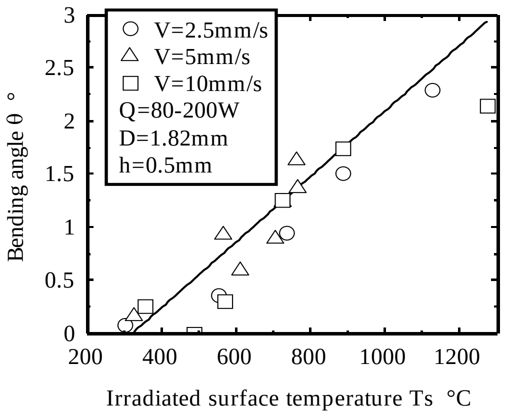

Fig. 7 Relation between Irradiated surface temperature and bending angle when varying laser power and feed rate

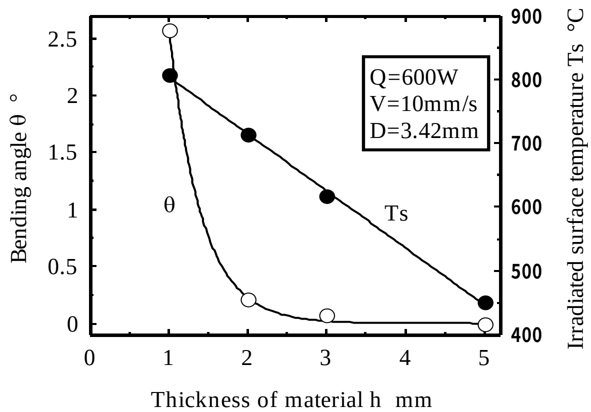

Fig. 8 Influence of thickness of material on bending angle and temperature

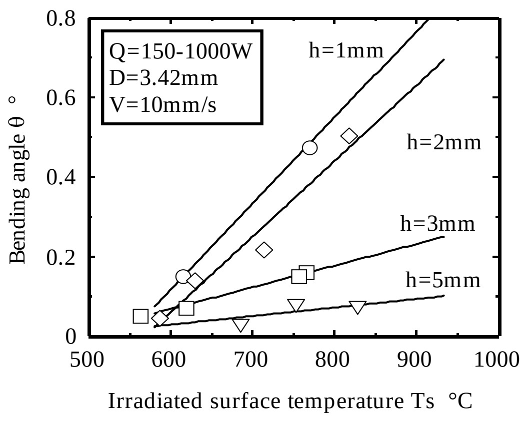

Fig. 9 Relation between Irradiated surface temperature and bending angle when varying thickness of material

the decrease of the irradiated surface temperature and the increase of flexural rigidity.

Fig. 9 shows the relation between the irradiated surface temperature and the bending angle in the various thickness of material. The bending angle becomes smaller, as the thickness of material becomes larger in the same temperature. It is found that the influence of the rigidity of material is strong. Therefore in this case, the bending angle cannot be predicted with only the irradiated surface temperature.

3.3 Influence of beam diameter on bending angle

Fig. 10 is the relation between the diameter of laser beam *D* and the width of deformed area *l* under the condition to generate same bending angle of about 12°. The width of deformed area increases linearly with an increase of beam diameter *D*.

Fig. 11 shows the influence of the beam diameter on the bending angle and the irradiated surface temperature. The irradiated surface temperature decreases with an increase of the diameter of laser beam *D* because of the decrease of energy density. Therefore the bending angle also decreases.

Fig. 12 shows the relation between the irradiated surface temperature and the bending angle in the various diameter of laser beam. The bending angle increases linearly with an increase of irradiated surface temperature in each diameter of laser beam.

Fig. 13 shows the influence of the diameter of laser beam on the bending angle in constant temperature of 800°C. It can be seen that the bending angle becomes larger, as the diameter of laser beam becomes larger in the same irradiated temperature. That is because the width of deformed area increases with an increase of beam diameter *D* shown as Fig. 10.

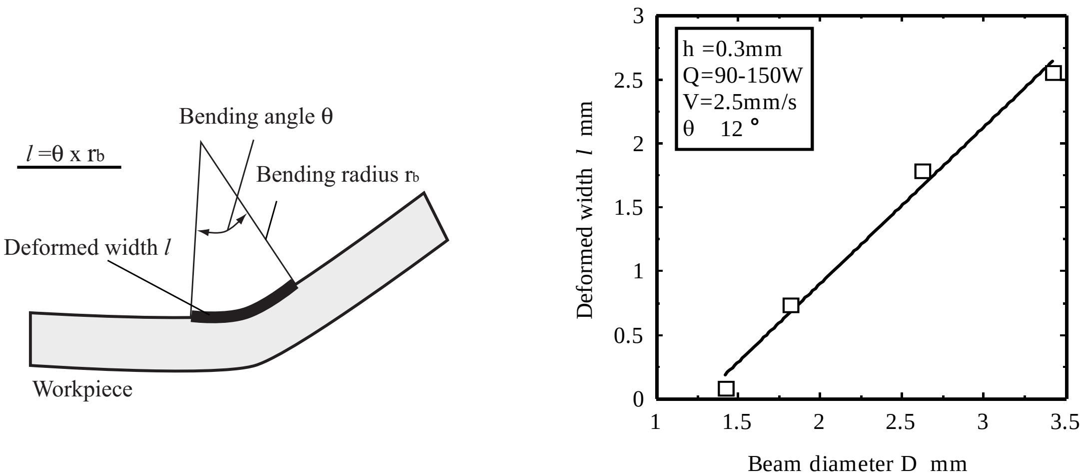

Fig. 10 Relation between beam diameter D and deformed area

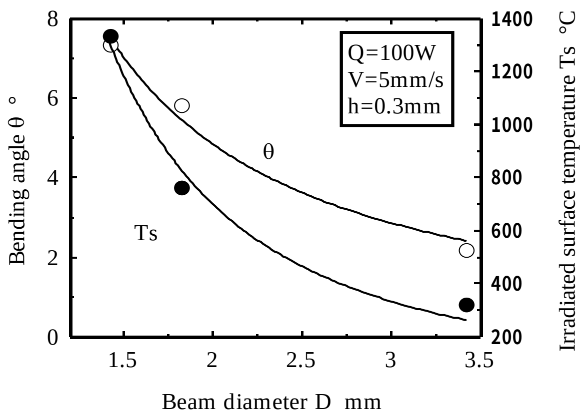

Fig. 11 Influence of beam diameter on bending angle and temperature

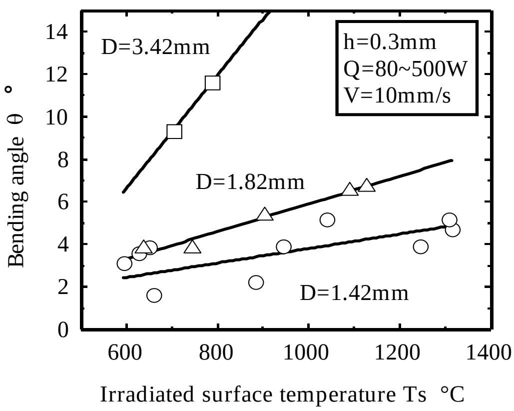

Fig. 12 Relation between Irradiated surface temperature and bending angle when varying beam diameter

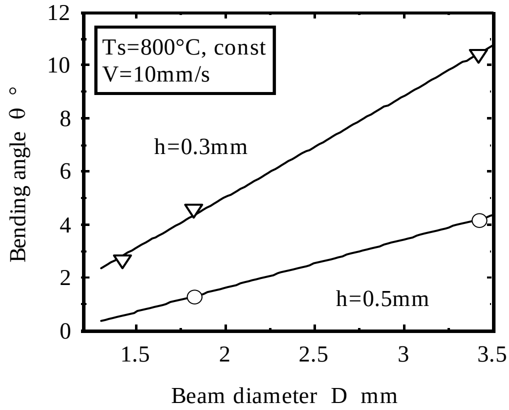

Fig. 13 Influence of beam diameterl on bending angle in constant temperature

4 CONCLUSIONS

Results obtained were as follows within the experiments carried out in this study.

1) The bending angle and the irradiated surface temperature increase with an increase of the laser power and the decrease of the feed rate. And the bending angle correlates with the irradiated surface temperature.
2) The increase of the thickness of material decreases the bending angle, because of the decrease of the irradiated surface temperature and the increase of the flexural rigidity.
3) The increase of the diameter of laser beam decreases the bending angle, because of the decrease of irradiated surface temperature. However, in the same irradiated surface temperature the increase of the diameter of laser beam increases the bending angle, because of the increase of the deformed area.

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