Experimental Investigation on the Bending Deformation of thin 1060 Pure Aluminum Sheet by Laser Peen Forming

Yongxiang Hu[1], Zhenqiang Yao[1], and Xiaoxia Xu[1]

1 State Key Laboratory of Mechanical System and Vibration, School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China

Abstract
Laser peen forming, is a purely mechanical forming method achieved through the use of laser energy to form sheet metal. This paper is based on recent experimental investigations on the laser peen forming of thin 1060 pure aluminum sheet carried out in order to understand the effect of process parameters such as laser intensity, number of scanning lines, scanning velocity on the bending deformation. Several thicknesses are selected for experiments. It is found that two bending direction, towards or away from the laser beam, can be obtained with different laser intensity for specimens with different thickness. And if decreasing the scanning velocity or increasing the scanning-line number, the bending angle is increased due to the increase of laser shocks.

Keywords: Laser Peen Forming, sheet metal, bending, laser intensity, thickness.

Introduction
Laser peen forming (LPF), a derivative of laser shock processing technology, is a locally effective forming process to form complex curvatures without dies. It is now emerging as a viable means for the shaping of metallic components. As shown in Fig.1 (a), the typical application of LPF is still carried out under a confined regime configuration. The specimen is undergo a high strain rate deformation and be dynamically yielded due to the rapid laser induced shock pressure. Different from common laser peening, the target is thinner and its bottom is typically not restricted just with one or two ends clamped in LPF. A schematic of LPF process is shown in Fig.1 (b). A large number of laser shocks are applied successively to the specimen surface according to the specified path. It will generate incremental deformations in the specimen, which can be accumulated to obtain large bending with convex or concave shape depending on the process parameters.

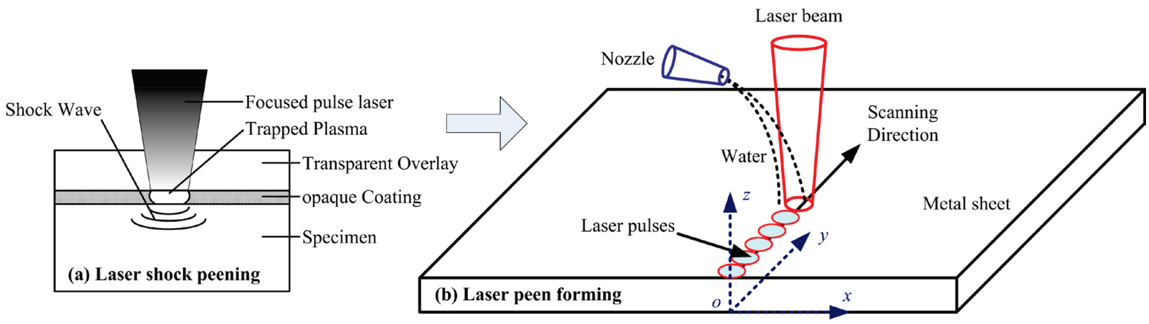


Fig.1 Schematic of the laser peen forming process

As a purely mechanical forming method, LPF has the advantages of laser thermal forming, such as non-contact, tool-free and high efficiency and precision. But its non-thermal process makes it possible to form without material degradation or even improve them by inducing compressive stress over the target surface, which is desirable because it is important in industry for shaped metal parts to resist cracks from corrosion and fatigue [1, 2].
The forming process of LPF has attracted many concerns of researchers. Hackle and Harris experimental demonstrated that it could contour the thick part over its large area and showed that an enhanced convex curvature was achieved[3, 4]. Ocana et al demonstrated

the suitability of laser micro-bending of thin metal strips to obtain a concave curvature bending[5]. Edwards et al investigated on the bending of a 75μm thick steel sample by LPF and the process was also found to produce a concave curvature[6]. Although several investigations have been paid on the LPF, further research work is still necessary on the relationships between bending deformation and process parameters.

In this paper, experiments are performed to understand the effect of process parameters such as laser intensities, scanning velocities and the number of scanning lines on the bending deformation of thin sheet metal with different thicknesses by LPF. Some interesting phenomenon are found and reported.

Experimental Methods

Fig.2 illustrates the experimental setup for performing the process of LPF. A Q-switched Nd:YAG pulsed laser Pro-290 are used for experiment. The wavelength of 532 nm is selected to enable the laser beam to propagate longer through water with lower absorption of beam energy. Also it is operated at the repetition frequency of 10Hz and the pulse duration about 10ns in FWHM. The laser power lever is controlled by using a mirror beam splitter. The laser beam is transmitted by three reflecting mirror to be vertical and then focused onto the target surface with the desired beam diameter. Three laser energies are chosen for experiments. One end of the target is clamped, and is mounted on a motor controlled X-Y table stage. The black tape, thick enough to maintain its integrity after irradiation of scanning laser pulses, is worked as the sacrificial overlay. And water is worked as the transparent overlay to confine the generated plasma.

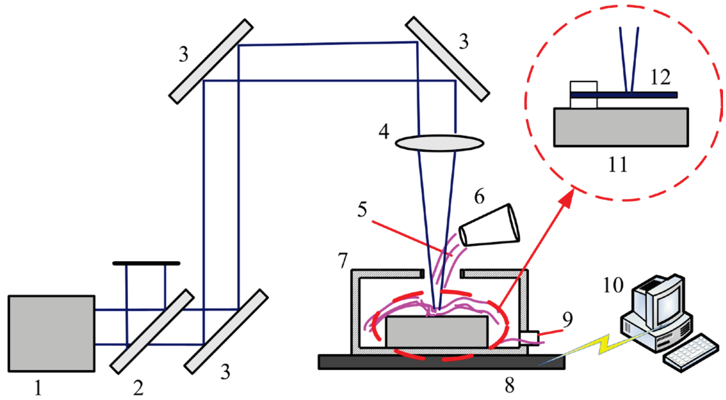


Fig.2 Schematic of experimental setup for laser peen forming: 1-Nd:YAG laser, 2-beam splitter, 3-reflecting mirror, 4-lens, 5-water, 6-nozzle, 7-container, 8-X/Y stage, 9-water outlet, 10-computer, 11-sample holder, 12-target

Commercial pure aluminum (1060 of 99.6 pct purity) sheets with different thicknesses are used as specimens. All specimens are acquired in the form of one thin plate at the same direction. As shown in Fig.3, the clamped width of specimen W_c is about 12.5mm and the distance W_d between the first scanning path and the clamped edge is about 4mm. Forming process in experiments is performed by coupled computer control of the continuous scanning velocity V_y at the width direction and the step interval Δx at the length direction. The specimen is scanned forward and backward by being moved at the width direction with respect to the stationary laser beam. Every step movement in the *x*-direction is triggered after a continuous movement with the specimen width in the *y*-direction. Multiple scanning lines with the number of N_x are applied with the same step interval in the length direction to enlarge the bending deformation. Different scanning velocities are used. Some key experimental conditions and specimen parameters are summarized in Table 1.

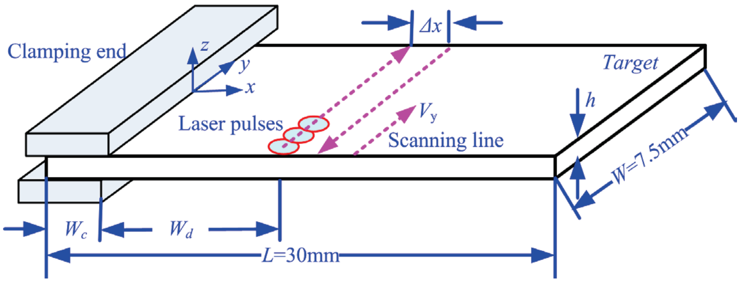


Fig.3 Configuration of specimens irradiated by laser pulses

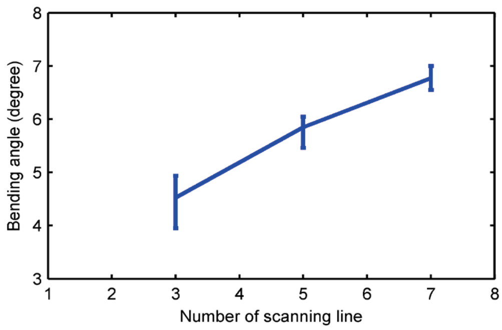
Table 1: Detailed experimental conditions

Parameters	Value
Laser intensity, I_0 (GWcm-2)	1.93, 3.85, 7.70
Beam diameter, Φ*D* (mm)	1.2
Scanning velocity, V_y (mms-1)	720
Number of scanning lines, N_x	3, 5, 7
Specimen dimension, *L*×*W* (mm)	30×7.5
Specimen thickness, *h* (mm)	0.5, 0.7, 1.0, 1.5, 2.0, 2.25

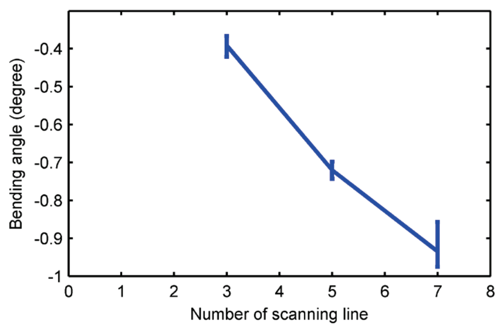
After experiment, bending deformation is mainly achieved around the y-axis into the z-direction. And the bending profiles of specimens are measured with a contactless image measuring system VGS BASIC300 with the accuracy about 5μm. All measurements are performed at the edge of bottom surface in the length direction. Bending angles are calculated based on the measured data about free end beyond laser shocks. The value of bending angle is assumed to be positive for the upward bending with a concave curvature and negative for the downward bending with a convex curvature.

Experimental Results

Two different bending directions can be found after LPF. Fig.4 shows the calculated bending angles generated by different number of scanning lines. With the same process parameters after seven scanning lines, the free end of specimen with the thickness of 0.5mm appears to bend upward towards laser beam to generate a concave curvature, while that with 2mm in thickness, appears to bend downward away from the laser beam to generate a small convex curvature.



(a)



(b)

Fig.4 The effect of scanning-line number on the bending, I_p=3.85 GW/cm^2, ΦD = 1.2mm, V_y=720mm/min : (a) 0.5mm thick target; (b) 2mm thick target

As shown in Fig.4, the experimental results also show that the bending angles increase almost linearly with the increase of scanning-line number for both two thickness specimens. The reason for this results can be attributed to the increased of laser shocks. Besides, we can also found that after being shocked with seven scanning lines, the bending angle is increased to about 6.77 degrees for 0.5mm thick sample with upward bending, while it is only -0.961 degrees for 2.0mm thick sample with a downward bending. The bending of 2mm thick sample is much smaller than that of 0.5mm thick samples under same experimental conditions. Large bending distortion is easier to generate with upward bending by LPF.

Fig.5 shows the relationship between the specimen thickness and the bending angle after seven scanning passes for three different laser intensities. From the results, it can be found that the bending angle is varying continuously and smoothly from the concave form to the convex with the specimen thickness increasing from 0.5mm to 2.25mm. By the increase of specimen thickness, bending angles are decreased for upward bending at first and then turn into being negative with downward bending. Therefore, it is possible for a piece of sheet with a specific thickness to remain flat after laser shock. In addition, the changing trends of downward bending by three laser intensities are different as following: for the low laser intensity of 1.93GW/cm^2, the downward bending is decreased by the specimen thickness; for the medium intensity of 3.85GW/cm^2, it is increased at first and then decreased; and for the high intensity of 7.70GW/cm^2, it is always increased.

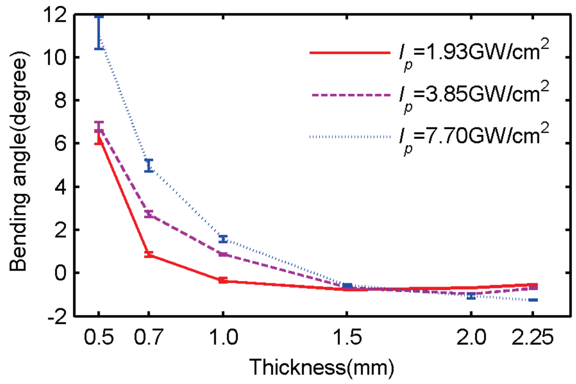


Fig.5 The effect of specimen thickness on the bending deformation of sheet metal with different laser intensities, ΦD = 1.2mm, V_y=720mm/min, N_x=7

Comparing the bending angles for specimens with the same thickness as shown in Fig.5, it can also be found clearly that the upward bending for specimens with the thicknesses of 0.5mm and 0.7 mm are always increased by the laser intensity. It is similar to the downward bending for specimens with the thicknesses of 2.0mm and 2.25mm. However, for specimens with two medium thicknesses of 1.0mm and 1.5mm, the results are different. To clearly demonstrate the relationship between the laser intensity and the bending angle, Fig.6 gives the results by making the laser intensity as the abscissa. It can be found that the downward bending for specimens with the thickness of 1.5mm is decreased by the laser intensity. Moreover, it can turn into the upward bending for specimens with the thickness of 1.0mm when the laser intensity increases from 1.93 GW/cm2 to 3.85 GW/cm2.

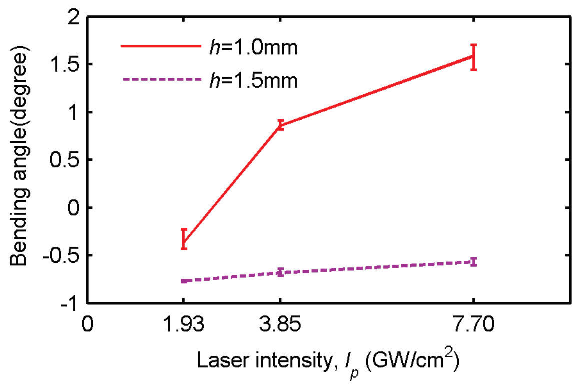


Fig.6 The effect of laser intensity on the bending deformation of sheet metal, ΦD=1.2mm, V_y=720mm/min, N_x=7

Fig.7 shows the effect of scanning velocities on the bending deformation of sheet metals with different thickness in the case of the laser intensity of 3.85GW/cm^2. As shown in Fig.7, the bending directions are not affected by the scanning velocity. Both the upward and downward bending are increased by the scanning velocity. Three curves for different scanning velocities are intersected at a common point, where the bending angle is about zero. It demonstrates that there is a specific thickness for a sheet to remain flat after laser shock again.

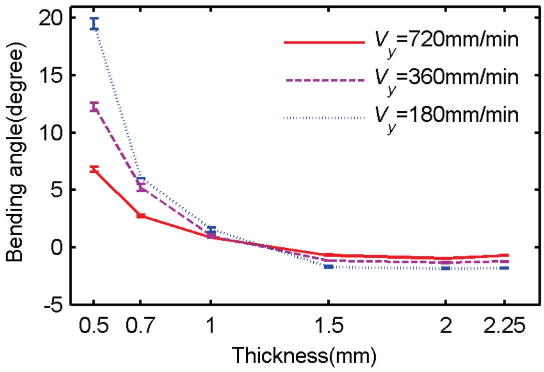


Fig. 7 The effect of scanning velocity on the bending deformation of sheet metal with different thickness, ΦD=1.2mm, I_p =3.85GW/cm^2, N_x=7

Discussion and Conclusions

Experiments on LPF have been performed to understand the effect of process parameters on the bending deformation of thin sheet metal with several thicknesses. The following conclusions have been reached:

(1) The sheet metal can be made to bend not only towards but also away from the laser beam depending on the specimen thickness and laser intensity. And the bending deformation is varied continuously and smoothly from the concave form to the convex by increasing the sheet thickness or decreasing the laser intensity.

(2) Increasing the number of scanning line or decreasing the scanning velocity can increase the bending deformation for both the upward and downward bending due to the increase of laser shocks, but they cannot change the bending direction.

(3) Both the existed specific thickness and the conversion from the downward bending to the upward by increasing the laser intensity imply that there is a specific condition to make a sheet remain flat.

The possibility of two bending directions is very useful for industrial application. In this way, laser peen forming can be extended to generate one-dimensionally convex or concave curved geometry, even multi-curvature complex geometries. Further invesigation should be paid intensively on the process planning.

Acknowledgements

The authors would like to thank the National Natural Science Foundation of China (Grant No. 50905109, 50821003), the Doctoral Fund of Ministry of Education of China (Grant No. 20090073110039) and the Research Fund of State Key Lab of MSV, China (Grant No.MSV-2010-12).

References

[1] H.S. Niehoff, F. Vollertson, *Laser induced shock waves in deformation processing*, METALURGIJA -Journal of Metallurgy. Vol. 11(2005), pp. 183-194.

[2] Y. Wang, Y. Fan, S. Vukelic, et al, *Energy-Level Effects on the Deformation Mechanism in Microscale Laser Peen Forming*, Journal of Manufacturing Processes. Vol. 9(2007), pp. 1-12.

[3] L. Hackel, F. Harris, *Contour Forming of Metals by Laser Peening*, U.S. Patent 6410884.
[4] L. Hackel, F. Harris, *Pre-loading of components during laser peen forming,* U.S. Patent 6670578.
[5] J.L. Ocaña, M. Moralesa, C. Molpeceresa, et al, *Short pulse laser microforming of thin metal sheets for MEMS manufacturing*, Applied Surface Science. Vol. 254(2007), pp. 997-1001.
[6] K.R. Edward, C. Carey, S.P. Edwardson, et al. *Laser Peen Forming for 2D Shaping and Adjustment of Metallic Components*, In: M.Geiger, A.Otto, and M.Schmidt (ed), Proceedings of the 5th Laser Assisted Net Shape Engineering, Meisenbach-Verlag, Bamberg, Erlangen-Nuremberg, Germany, 2007.