Laser Bending of Stainless Steel Sheet Metals

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ABSTRACT: Laser forming is an innovative technology that uses a laser beam to form sheet metal by thermal stresses and is well suited for short production runs, eliminating the need for expensive dies and reducing the cycle time. High power diode lasers have entered the industrial manufacturing area, because of their unique features (small size and low weight), high efficiency and reliability; nowadays, diode lasers have gained high interests as new sources for material processing. Many industrial applications are possible, from brazing to cladding and hardening. As a consequence of the rather poor beam quality, applications as cutting and high speed deep penetration welding are not yet possible, but laser forming can be effectively performed. Due to its low specific power, diode laser bending can be performed under focalization conditions, contrary to the other laser sources (such as CO_2 laser). In this study, a high power diode laser was used to form AISI 304 sheet metals. This laser had a rectangular spot that was focused on the specimen to bend; the short side of the spot was aligned with the laser scan direction. The laser power ranged from 100 to 300 W (with an increment of 50 W); two scan rates were used, 4 and 8 mm/s, and the number of passes was 2, 4 or 6. At lower values of laser power the bending angle tends to be negligible; at higher values material melting occurs, and, as a consequence, process effectiveness falls down. In the experimentation, the values of bending angle, microstructure and residual stresses of the stainless steel sheet metal laser bent were analyzed with regard to the input variables.

Key words: Laser bending, Sheet metal, Diode laser, Stainless steel

1 INTRODUCTION

Laser forming is a new and very promising technique for metallic component shaping. It allows high automated manufacturing processes to occur and to reduce tooling costs for rapid prototyping. The process offers a great flexibility as a lot of other applications (such as soldering, brazing and hardening) can be performed by means of the same apparatus. The number of industrial applications of laser forming is continuously increasing, due to the possibility of forming highly accurate sheet metal products in a cost effective way. [1]

Particularly, diode lasers have some industrial advantages compared with other laser systems: lower cost and higher efficiency, which permits lower electrical energy consumption. The reduced size allows an easier integration in production lines. Cutting and high speed deep penetration welding are not possible for diode laser, due to the low specific power, but aesthetic welding, brazing, hardening, soldering, cladding and polymer welding are already good industrial application fields for diode lasers. [2]

In the traditional metal forming a sheet metal is plastically deformed when it is subjected to stress that is greater than the yield point. In the laser forming process, the plastic deformation occurs by the thermal stresses introduced into the surface of a metal sheet during the laser heating and subsequent cooling. The process configuration is shown in Fig.1

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2 EXPERIMENTAL PROCEDURE

The tests were performed focusing the diode laser on AISI 304 stainless steel with 100x35 mm^2 area and 1.20 mm thickness. Before testing, samples were cleaned by means of methanol to remove any unwanted grease stain. No coating was applied on the sheets.

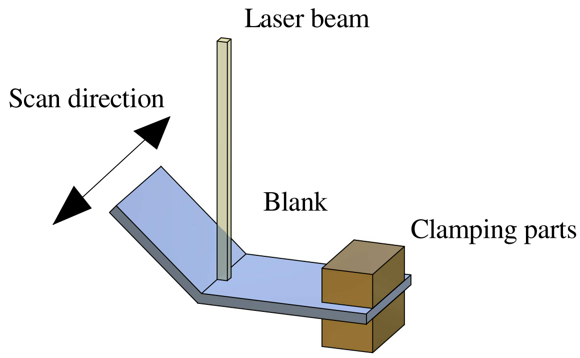

Fig. 1. Schematic view of laser bending

Metal sheets were fixed on a CNC motion table. The samples were then laser scanned forward and backward by moving them under the motionless laser source. Each scan was 55 mm long, i.e. 20 mm longer than the sample length. In this way the motion inversion occurred externally to the sample, avoiding over-heating on the edges. [6]
Table 1 reports process parameters employed for experimentation and experimental results.
X-ray diffraction method was used for study the level of the inner first and second order residual stresses. X-ray diffraction method is one of very usefully technique in order to detect the changes in lattice of the superficial layer subjected to different damage processes. These changes could be: type of phase, crystalline lattice constants, dimension of mosaic blocks, level of the inner first and second order tensions, degree of texture, the thickness of superficial layer, the cohesion forces between atoms, level of dislocation density, etc. [4]
In this study, the analysis of the superficial layer of laser bending sample in the opposite side action of the laser beam was performed on the X-ray diffractometer DRON 3 equipped with a graphite crystal monochromator. Only three specimens, i.e. 10, 13 and 16, were analysed [5]

Table 1. Experimental parameters and results

Specimen	Power, [W]	Speed, [mm/s]	Passes	Bending angle, [^{0}]
1	100	4	2	1,42
2	100	4	4	3,47
3	100	4	6	5,45
4	150	4	2	3,38
5	150	4	4	9,22
6	150	4	6	14,02
7	200	4	2	melting
8	100	8	2	0,8
9	100	8	4	1,62
10	100	8	6	3,57
11	150	8	2	2,52
12	150	8	4	5,00
13	150	8	6	21,40
14	200	8	2	4,17
15	200	8	4	9,92
16	200	8	6	8,53
17	250	8	2	melting
18	300	8	2	melting

The specimens 10, 13 and 16 from table 1, were scanned in angular domain, 2Θ, where X-rays diffraction appears (λ = 1,541 Å), that is characteristic to γ-Fe phase in stainless steel.
For structure analysis, the same samples as for X-ray analysis were prepared. The specimens were electrochemical eroded. The observations upon the structure were made using a microscope Neophot 2, at a magnitude of 200:1.

3 RESULTS AND DISCUSSION

3.1 Bending angle

The bent samples were measured using microscopy.
As it results from table 1, next observations could be made:
- to the same speed, when the power and the number of passes are increasing, the bending angle is increasing;
- when the laser power is bigger then 200W, is possible to appear the melting phenomenon, even when the number of passes is small;
- to the same number of passes and the same speed, with the power increasing, the bending angle has a nonlinear variation. Considering three specimens, deformed in the above experimental conditions, figure 2 presented this variation.

3.2 X-ray analysis

X-ray diffractograms of the initial surface as well as of the three laser machined AISI 304 for different laser power and the same speed and number of passes, are shown in Fig. 3, using arbitrary units. The diffractograms were recorder with a velocity of 720 mm/h.

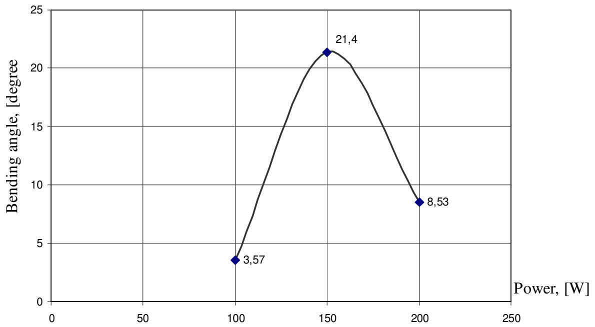

Fig. 2. Bending angle variation for different laser powers, speed 8 mm/s, 6 steps

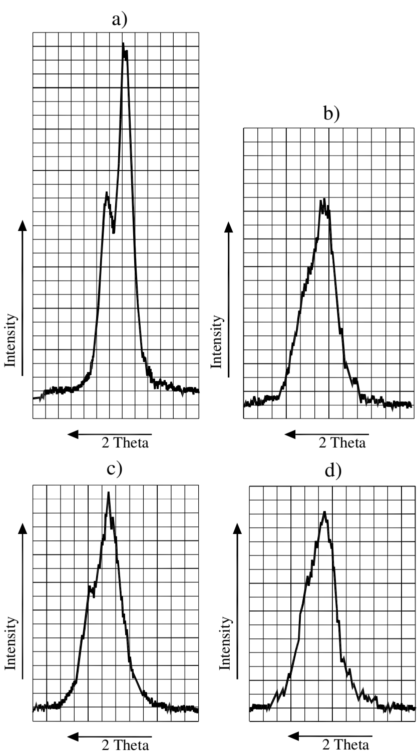

Fig. 3. X-ray diffractogram of the laser machined AISI 304, speed 8 mm/s, 6 steps: a. initial state; b. 100 W laser power; c. 150W laser power; d. 200W laser power (arbitrary units)

The first order inner tensions, σ_I, are given by the relation:

$$\sigma_I = \frac{E}{\mu}(ctg\theta_s)\Delta\theta \tag{1}$$

where E is the Young Modulus; μ – Poisson Coefficient; θ_s – diffraction angle measured on the stressed sample; $\Delta\theta$ – diffraction angle variation given by relation:

$$\Delta\theta = \theta_s - \theta_{st} \tag{2}$$

where θ_{st} is the diffraction angle measured on the initial sample.

The amount of second order inner tensions, σ_{II}, was evaluated using the physical width of the diffraction line (311), β_{311}, knowing that:

$$\sigma_{II} = \frac{E}{\mu}\eta_{331} \tag{3}$$

where η_{331} is a measure of the interplanar distance non-homogeneity given by relation [5]:

$$\eta_{331} = \left(\frac{\Delta d}{d}\right)_{331} = \frac{\beta_{331}}{4tg\,\theta_{331}} \tag{4}$$

$$\beta_{331} = \sqrt{(\beta_{331})_s^2 - (\beta_{331})_{st}^2} \tag{5}$$

where $(\beta_{331})_s$ is the width of diffraction line (331) from stressed sample, while $(\beta_{331})_{st}$ is the same parameter from standard sample.

The analysis of the diffractograms has shown that the first order inner tensions, σ_I, measured on the convex exterior surface of the sample, in the laser beam action zone, have a non-linear variation (fig. 4). The figure presents only the variation of the product $(ctg\theta_s)\Delta\theta$ who is proportional according with the relation (1) with the first order inner tensions, σ_I.

First, with the laser power increasing, the first order inner tensions decrease, because the thermal effect is more pronounced than the mechanical effect and lead to their release. Forwards, with the laser power increasing, the first order inner tensions increase, which means that the mechanical effect becomes dominant due to high cooling temperature gradient. This could be put in accordance with the bending angle variation, see figure 2.

The second order inner tensions, σ_{II}, have a stabilization tendency, along with the laser power increasing, which means that the two effects, mechanical and thermical, are mutually compensated (fig. 5). Figure presents the variation of the physical width of the diffraction line (311), β_{311}, which is proportional according with relation (3) with the second order inner tensions, σ_{II}.

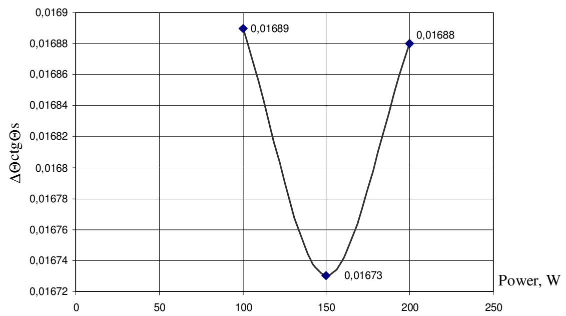

Fig. 4. The first order inner tensions variation for different laser powers, speed 8 mm/s, 6 steps

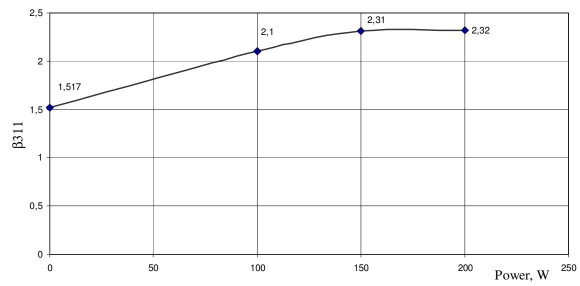

Fig. 5. The second order inner tensions variation for different laser powers, speed 8 mm/s, 6 steps

3.3 Microscopic analysis

The structure of stainless steel, in the three measured specimens, is affected by the laser beam, and it appears annealing twins. The annealing twins appearance takes place on the concave region of the bended specimens, in the region of laser beam direct action (fig. 6). With the laser power increasing, the density of the annealing twins is increasing, as well as the depth of their penetration.

4 CONCLUSIONS

At lower values of laser power the bending angle tends to be negligible; at higher values material melting occurs, and, as a consequence, process effectiveness falls down. In the experimentation, the values of bending angle, microstructure and residual stresses of some stainless steel sheet metal laser bent were analyzed with regard to the input variables.

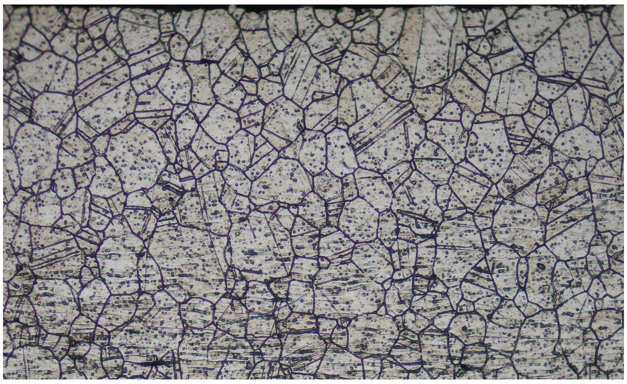

Fig. 6 Annealing twins in laser bending structure, laser power 200 W, speed 8 mm/s, 6 steps, magnitude of 200:1

ACKNOWLEDGEMENTS

The work reported here was an activity in the frame of the next CEEX Romania Programs: Contract CEEX_M3, PR-D04-PT00-30/2006 – Development of a collaboration network in the field of unconventional technologies and CEEX-P-CD no. 130/2006 – Materials and technologies for plane and spatial profiling. The Romanian authors appreciate the effort made by our Italian partners in providing the lasers samples.

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