

Norbert Radek  [orcid.org/0000-0002-1587-1074](https://orcid.org/0000-0002-1587-1074)

Piotr Kurp  [orcid.org/0000-0002-1001-5033](https://orcid.org/0000-0002-1001-5033)

Faculty of Mechatronics and Mechanical Engineering, Kielce University of Technology

Jacek Pietraszek  [orcid.org/0000-0003-2851-1606](https://orcid.org/0000-0003-2851-1606)

[jacek.pietraszek@mech.pk.edu.pl](mailto:jacek.pietraszek@mech.pk.edu.pl)

Institute of Applied Informatics, Cracow University of Technology

## LASER FORMING OF STEEL TUBES

### KSZTAŁTOWANIE LASEROWE RUR STALOWYCH

#### Abstract

The paper presents a study on microstructure and microhardness changes obtained in the spun carbon steel tube after shaping by a laser beam. The surface of a pipe was machined circumferentially using a 1500 W CO<sub>2</sub> laser beam at various diameters (distance from the focus). As a result, plastic deformations such as convex and narrowing shape changes were observed. The conducted research, including microhardness measurements, shows that, in comparison to the unprocessed material, the microstructure was significantly changed, both in the convex and narrowed layer.

**Keywords:** laser forming, tube, carbon steel

#### Streszczenie

W pracy przedstawiono badania zmian mikrostruktury i mikrotwardości warstwy wierzchniej wyoblonej i przewężonej rury ze stali węglowej po laserowym kształtowaniu. Powierzchnia rury była skanowana po obwodzie wiązką lasera CO<sub>2</sub> o mocy 1500 W przy różnych średnicach (odległościach od ogniska). W efekcie uzyskano odkształcenia plastyczne, takie jak wyoblenie i przewężenie rury. Przeprowadzone badania, w tym pomiary mikrotwardości, wykazują, że mikrostruktura uległa istotnej zmianie w stosunku do materiału rodzimego, zarówno w warstwie wyoblonej, jak i przewężonej.

**Słowa kluczowe:** kształtowanie laserowe, rura, stal węglowa

## 1. Introduction

Laser technologies are currently extensively utilized in manufacturing, technology and healthcare. In technical practice, a laser technology is used mainly for cutting, welding and surface modification [1–3]. However, there is another technology that is relatively weakly known and it is an advantageous utilization of a laser beam to shape materials, known as the laser forming [4].

The current typical industrial practice of material shaping requires the use of a press equipment and high-strength tools for pressing and bending. The production of these tools requires materials of much higher quality and very high accuracy, which results in their high price and, finally, a large cost of the whole forming process. Bending tools are usually specific, not universal, and can be used cost-effectively only in large series processes, whereas the laser forming process is completely different, as changing the shape of a workpiece requires only a change of the control program, not the machining equipment. It means that laser-based bending is suitable for a small-lot production or almost single-unit production. Additionally, the laser forming process may be used to create shapes that cannot be obtained by other technologies.

The laser forming process creates thermal stresses on the surface of a workpiece. Internal stresses cause plastic deformation, bending or shortening of a material. A laser beam hits the surface of a part, making the material heat up locally at the point of the impact. The heat from the laser beam causes thermal expansion of the material, which in turn causes a change in the shape of the part. The key issue, which has to be resolved to achieve the desired shape changes in the laser forming technology is to determine the path and technological parameters of a laser beam.

This technology may be used in various ways. The power of a laser beam, its wavelength, the diameter of a laser spot on the surface of a material and the path feed rate are basic parameters of the laser forming process. By hitting the surface of a workpiece, a laser beam initiates three different deformation mechanisms which can be active separately or in combination:

- ▶ the temperature gradient mechanism (TGM) [5], mainly used to produce precise small bend angles in thick sheets,
- ▶ the buckling mechanism (BM) [6, 7], usually used for bending of thin metal sheets,
- ▶ the upsetting mechanism (UM) [7, 8], also called a shortening mechanism, used to form a plane sheet into a specially formed part, the shortening of small frames or aligning in microparts operations.

Rarely, more controversial phase transition mechanism [9, 10] is considered.

## 2. Materials and treatment parameters

The pipes used in the experiment were made from the S235 carbon steel. The tube dimensions were the following: the length of 300 mm, the diameter of 45 mm and the wall thickness of 1.5 mm. Before the experiment, the sample was checked to be free of dirt and next the surface of the pipe was coated with a thin film of a special absorber to increase the absorption coefficient.

A CO<sub>2</sub> laser TLF 6000 TURBO was used for the experiment with the following parameter settings:

- ▶ continuous mode,
- ▶ wavelength  $\lambda = 10.6 \mu\text{m}$ ,
- ▶ efficiency  $\eta = 7\%$ ,
- ▶ maximum power  $P = 6000 \text{ W}$  (power used for the experiment  $1500 \text{ W}$ ).

A stationary unfocused laser beam with a power of  $1500 \text{ W}$  was set perpendicularly to the surface of the tube. The tube was rotated at  $5 \text{ rpm}$  (Fig. 1). Simultaneously, the laser-heated material was cooled by water spraying (water temperature  $18^\circ\text{C}$ ) to maintain the proper temperature distribution. The distance from the focus of the beam was systematically increased to achieve a gradually increased laser spot. The thermal stresses, created inside heated tube, caused the shape change.

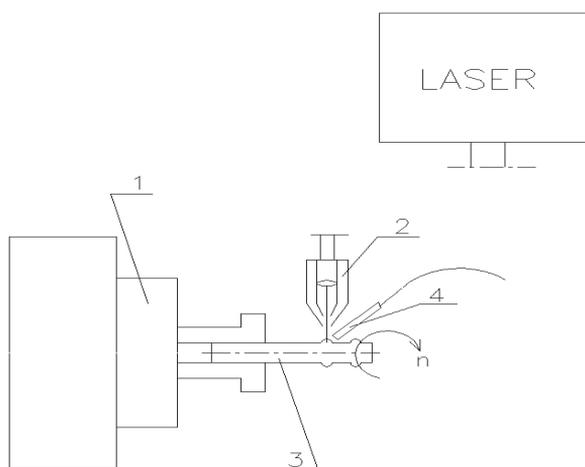


Fig. 1. The scheme of the tube laser forming: 1 – a spindle, 2 – a laser head, 3 – a tube, 4 – a pipe with a cooling liquid

The tube shaping led from the original diameter of  $\phi 45 \text{ mm}$  to the reduced one of  $\phi 44.2 \text{ mm}$  in the neck and to the increased one of  $\phi 51.45 \text{ mm}$  in the greatest widening. Three specimens were taken from the mentioned places for hardness measurements and the evaluation of the metallographic microstructure:

- ▶ the first sample is an unprocessed material (unaffected by the laser beam action),
- ▶ the second sample is from the neck (diameter of  $\phi 44.2 \text{ mm}$ ; a distance from the focus –  $50 \text{ mm}$ ),
- ▶ the third sample from the greatest widening (diameter of  $\phi 51.45 \text{ mm}$ ; a distance from the focus –  $150 \text{ mm}$ ).

The metallographic evaluation was performed on a JOEL JSM-5400 device. The hardness measurements were carried out according to the Vickers method with a load of  $0.1 \text{ kG}$ . A microstructure analysis was conducted for specimens using a Joel JSM-5400 scanning electron microscope.

### 3. Results and discussion

The microstructure of the unprocessed carbon steel consisted of ferritic and pearlitic grains (Fig. 2). It is characteristics of the eutectoid steel microstructure. In the processed material, the growth and orientation of the granular homogeneous cylindrical grains (Fig. 3) refer to the direction of heat transfer and the activation of many mechanisms of the laser forming.

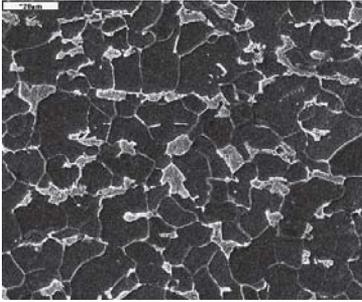


Fig. 2. The microstructure of the carbon steel

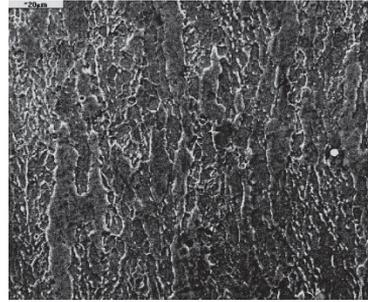


Fig. 3. The grain orientation caused by heat dissipation

Micro cracks with the length of about 0.17 mm were also observed (Fig. 4) in the lower layer. They may have been caused by:

- ▶ the occurrence of tensile stresses in the final stage of the process at the bottom of the layer,
- ▶ large temperature gradients and the low coefficient of a thermal conductivity ( $k = 50 \text{ W/m}^{\circ}\text{K}$  for S235 carbon steel, decreases with the increasing temperature).

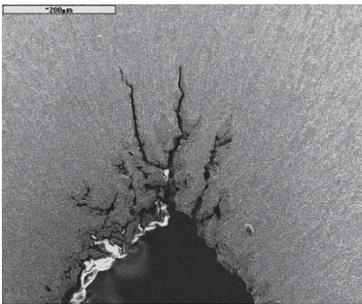


Fig. 4. Microcracks after laser forming

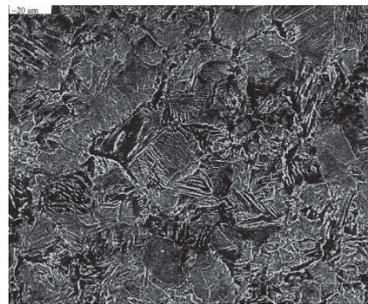
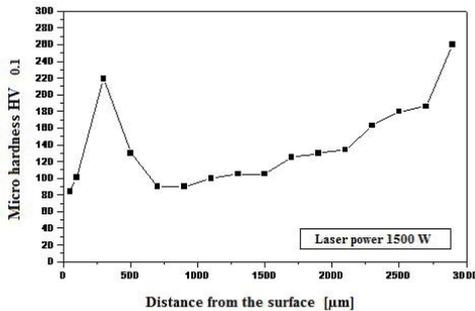
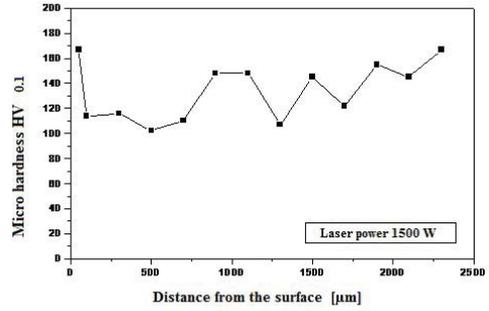


Fig. 5. Bainite microstructure

In the heat affected zone (HAZ), the following microstructures were observed: bainite, ferrite-bainite and pearlite. The bainite detection in HAZ (Fig. 5) is an indication of rapid heating and cooling of the material, because bainite creation is associated with them.



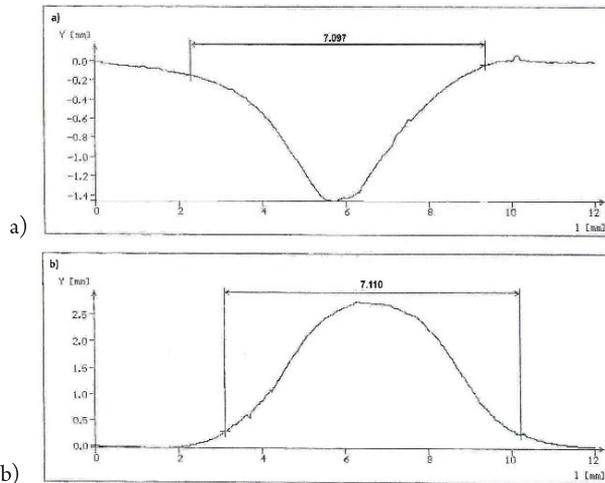
a)



b)

Fig. 6. Microhardness measurements for the tube after laser forming

The second set of microhardness measurements was made on both sides of the bent parts. The analysis of the obtained dataset showed that the microhardness of the concave layer (Fig. 6a) is higher than the microhardness of the convex layer (Fig. 6b).



a)

b)

Fig. 7. Changes of the pipe dimension as versus of the laser diameter: a) contracted layer, b) spun layer

The maximum measured microhardness was approx. 260 HV<sub>0.1</sub>, while the microhardness of the base material equaled 80 HV<sub>0.1</sub>. The changed shape of the spun tube was precisely measured by a PG2/200 shape analyzer. It allowed for the determination of the following dimensions of the formed tube:

- ▶ the radius of spinning,
- ▶ the angle of spinning,
- ▶ the width of the spun zone.

The geometry of the tube areas changed in the process and is presented in the formograph (Fig. 7), which shows a lack of the symmetry in the cross-section. One-sided fixing of the tube was a probable cause of this phenomenon.

## 4. Summary

The laser forming process affects the structure and the hardness of a material. The experiment showed that the structure changes of the S235 carbon steel occurred at the location affected by a laser beam. The microhardness measurements found that the increased hardness of the material is a result of a combined laser-based heating and simultaneous liquid-based cooling. This phenomenon seems to be similar to induction hardening – in both situations heating and cooling rates are high. The ability to manage structural and phase changes should allow for the formation of tubes with the desired mechanical properties. The laser forming process appears to be a promising technology for a small series production, but its use in industry will depend on eliminating its adverse effects, particularly microcracks. The simplest solution to prevent microcracks is the process is to slow down, but it reduces the competitiveness of the process compared to traditional methods of metal forming.

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