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ASPECTS REGARDING THE POSSIBILITY OF INCREASING HARDNESS ON A LOW CARBON STEEL ST37-2 BY SURFACE TREATMENT WITH CO_2 LASER

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This paper is presenting an interesting subject from the technological point of view regarding the possibility of a local hardening on pieces made from ST37-2 by applying a laser surface treatment on a well defined zone. The paper is presenting a study of the hardening effects on a low carbon steel ST37-2. By varying the laser process parameters the result was an increase in hardness, from 150 HV_1 in the initial base material, to 550HV_1 in a layer with the depth of 500 µm.

Keywords: heat treatment, CO_2 laser, surface heat treatment, ST37-2 steel

1. Introduction

The heat treatments applied on steels can lead to an improvement of properties and characteristics of the treated material. Laser treatment realized on material surface is based on the possibility of generating high and controlled energy densities that can be applied on well defined areas with small depth. The energy absorbed by material can be transformed into thermal energy, leading to local heat treating or melting, producing phase transformations. The effect of rapid cooling after heating, can promote the appearance of some microstructures with high hardness values (Fig. 1).

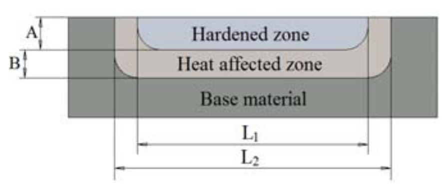

Fig.1. Hardening with laser. A – depth of hardened zone, B – depth of heat affected zone, L1 width of hardened zone, L2 – width of heat affected zone.

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Surface heat treatment shows a considerable interest today because it allows reconstruction of parts from strategic materials or allows improvement of the hardness and wear resistance [1, 2]. Due to high operation costs, manufacturing processes using laser are limited to special applications, where precise depth of intervention and value of energy input must be kept within very tight limits.

As an unconventional heat treatment, hardening with laser consists in a local heating followed by a rapid cooling of the material's surface, from a temperature situated above the phase transformation point, but without reaching the melting temperature [3,4].

Laser hardening process is applied in order to obtain higher values of mechanical and physical characteristics on material's surface, such as: hardness, surface quality, corrosion resistance and other physicochemical properties [5].

The advantages of laser surface hardening are given by the precise positioning and selection of heat treatment areas, precise control of heat treatment's depth, high processing speed and lack of technological cooling liquid [6-12].

2. Theoretical consideration

To estimate the penetration depth some formulas based on isothermal distribution of temperatures that is obtained as an effect of surface treatment can be used. In the case of laser surface treatment the equation for bi-dimensional propagation of heat can be used, from which can be estimated the penetration depth of treated area, by calculating the cooling time $t_{8/5}$ [8]:

$$t_{8/5} = (4300 - 4.3 \cdot T_0) \cdot 10^5 \cdot \frac{Q^2}{d^2} \cdot \left[\left(\frac{1}{500 - T_0} \right)^2 - \left(\frac{1}{800 - T_0} \right)^2 \right] \cdot F_2 \quad \textbf{[s]} \qquad \textbf{(1)}$$

where $t_{8/5}$ = cooling time between 800˚C and 500˚C [s]

T_0 = initial temperature of the base material [˚C]

d = the depth of the treated area [mm]

F_2 = shape factor that takes into account the deviations from the idealized physical model (for depositing a layer on a plate it is equal to 1) [14]

Q = input energy [kJ/mm]

To determine the optimum values of the regime parameters for CO_2 laser surface treatment different values of depth penetration have been calculated using a constant value of $t_{8/5}$, for steel ST37-2 (table 1)

Table. 1.

Calculation values of the depth of treated area using different values of linear energy

$t_{8/5}$[s]	T_0[˚C]	Q[kW/cm^2]	d[μm]
0.8	17	4.2	157.32
0.8	17	6.3	235.98
0.8	17	8.41	315.01
0.8	17	10.51	393.67
0.8	17	12.61	472.33

3. Experimental procedure

In order to study the effects of laser surface treatment some samples (plate type) were used, with sizes 60x100x5mm, made from a low carbon steel ST37-2, whose chemical composition is shown in Table 2. Process parameters used in laser processing were: Power density (having values between 4.2kW/cm^2 and 12.61 kW/cm^2), laser beam speed (having values between 1 – 6 mm/s) and a constant value of laser spot diameter (1mm).

Table 2

Chemical composition of low carbon steel ST37-2 DIN 17100

Chemical elements	C≤ 16mm max	C>16mm max	Si max	Mn max	P max.	S max.
wt.%	0.17	0.17	--	1.40	0.045	0.045

The cooling time $t_{8/5}$ is frequently used to characterize the thermal cycle for the metallic component submitted to heat treatment, in this way allowing the calculation of penetration depth and estimation of the effects of phase transformations that may appear during the heat processing [11, 12, 13, 14].

The cleaning of parts surfaces that undertake the laser heat treatment must be performed with extreme care in order to ensure the removal of impurities such as dust, paint, grease, traces of water, etc. These impurities are quickly evaporated by laser beam energy and may lead to formation of numerous defects such as craters, oxidation of the surface, porosities, and cracks [15].

In order to point out the hardening level of heat treated zone, microhardness measurements were performed using Matsuzawa MXT30 microhardness tester, with a force of 1kgf. The hardness was measured in the three characteristic areas, respectively: base material, heat affected zone and treated zone. For each zone 10 imprints were made, and later the arithmetic average was calculated. For base material (steel ST37-2) average hardness was Hvmed = 150 HV1. The penetration depths of the zones that were laser heat treated were measured by the optical macroscopy (Fig. 2), using an Olympus GX51 optical microscope equipped with image analysis software AnalySis.

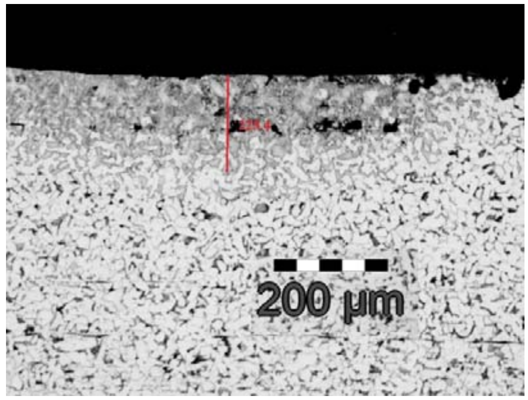

Fig. 2. Macroscopic analysis of an area treated with CO_2 laser, Power density 6.3 kW/cm^2, 20x.

4. Results

After analyzing the experimental data it was found that for values of power density that are under 4.2 kW/cm^2 for all displacement' laser speeds used, a heat treated area was not obtained, but only a heat affected zone with surface oxidation effects (Fig. 3).

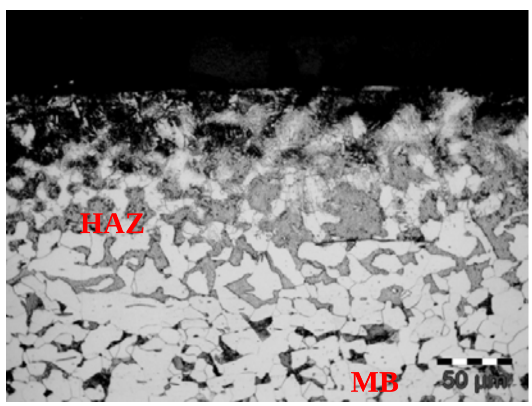

Fig.3. Macroscopic analysis of a heat treated zone with the CO_2 laser, the power density 4.2kW/cm^2 and the laser beam speed 3 mm/s.

When applying a higher power density of 4.2 kW/cm^2 in the microstructure, martensite and residual austenite (zone A - heat treated), ferrite and pearlite (zone B - heat affected) and ferrite and Pearlite (zone C - heat unaffected base material) were obtained (Fig. 4).

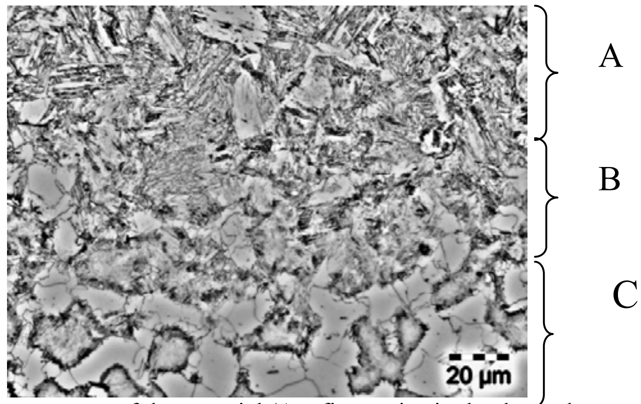

Fig.4. Granular structure of the material (A – fine grains in the thermal treatment zone, B – transition zone or heat affected zone – HAZ and C – base material).

By measuring the penetration depth resulting from the application of laser heat treatment a comparison of its effects on the treated zone could be done, using equation 1 (Fig. 5).

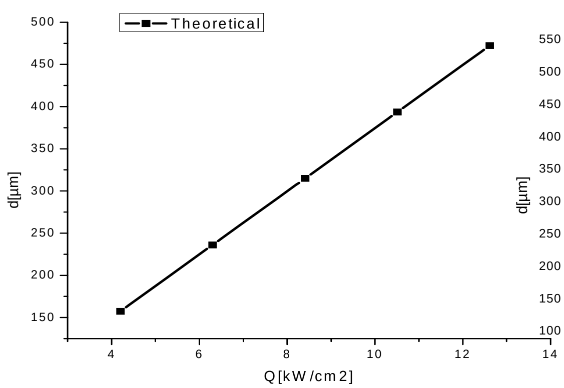

Fig.5.a)

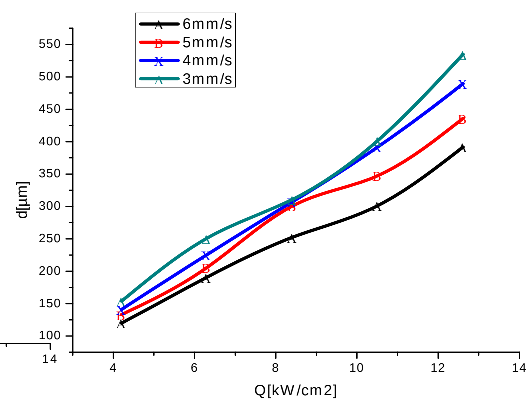

Fig.5.b)

Fig.5. Evolution of penetrations depth calculated theoretically a) and experimentally b) as a function of measured depth after performing a laser surface treatment.

It has been observed that for a constant value of 0.8 s for $t_{8/5}$ the theoretical depth varies linearly with the laser beam power, while in the experimental model an exponential variation with limits of variation positioned near to the theoretical curve appears. After performing a correct heat treatment and measuring the hardness of the treated areas, a Gaussian shape of the distribution of the measured values was obtained (Fig. 7), while in the case of the formation of a molten zone, an anomaly in the distribution of data (Gaussian bell) was obtained (Fig. 8).

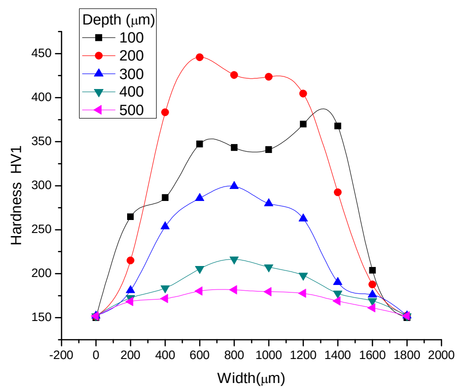

Fig.7. Power density 8.41 kW/cm^2, speed 2 mm/s

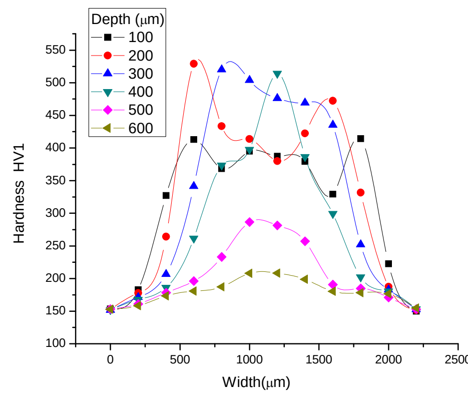

Fig.8.Power density 12.61kW/cm^2, speed 3mm/s

It was found that with increasing speed hardness increases, but Gaussian bell shape changes due to the extension of the molten zone. The evolution of the average values of hardness depending on the power density is presented in Fig. 9.

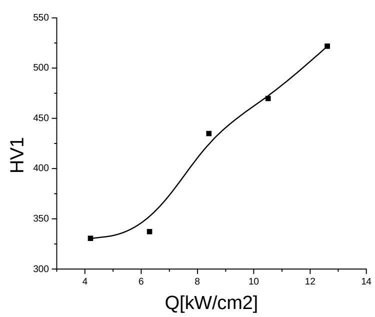

Fig.9. Hardness evolution depending on the power density

The best results were obtained for values of displacement speed of the laser beam between 4mm/s and 3mm/s (Fig. 10), for which penetration depths up to 400-500 μm and a change of crystalline microstructure of the material were obtained. Observations are supported with microhardness measurements, confirming the phase transformations occurring in the material by increasing the hardness of the material in the layer heat treated up to 465 HV_1.

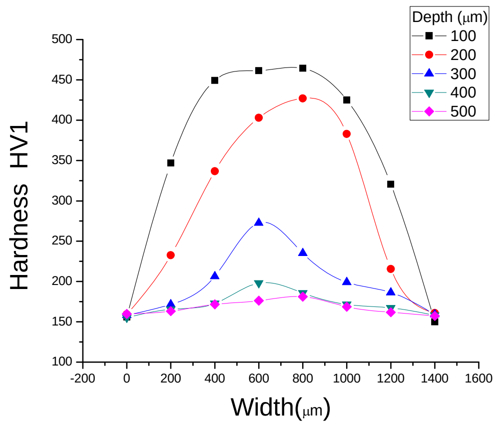

Fig. 10. Power density 8.41 kW/cm2, speed 3 mm/s

6. Conclusions

The experimental researches on ST37-2 steel showed that hardening of surfaces is possible using laser radiation for this type of material. Tests and investigations have allowed to establish the optimal process values, respectively: speed and power required to achieve the desired results.

By increasing the speed of the laser beam movement, a significant decrease in the penetration depth of heat treated zone is obtained. At the same time, increasing power density of the laser beam an increase in the depth of the heat treated zone is obtained (fig.5).

For a power density of the CO_2 laser that exceeds 10.51 kW/cm^2 the effect is melting of the base material ST 37-2. This results in a hardness that doesn't present a perfect Gaussian distribution (fig.7).

The results offer an encouraging perspective regarding the use of this low carbon steel grade in different applications, other than classical ones, as structural steel, and further studies of practical applicability are necessary to confirm the results presented in this paper.

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