The using of laser radiation at surface hardening of improvement steels

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The paper aims the influence of the laser radiation parameters on superficial layers of carbon and alloy improvement steels. Geometry and depth of penetration of radiation effects are studied by optical and electronic microscopy. It aims also the distribution of components on the affected film thickness by laser energy, analyzed by EDAX and variation of mechanical properties.

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1. General considerations

Researchers have studied the influence of laser radiation parameters on surface hardening under various aspects. By comparing different techniques of laser surface hardening for different types of steel, it has been established the bond between the effects of laser radiation on the microstructure in a material and the depth profiles of microhardness [1].

Surface hardening by heating the metal surface with a laser beam of high specific capacity, is based on a local heating effect, followed by rapid cooling to a hight hermal gradient dT / dt . The purpose of this treatment, just as in conventional quenching, is the obtaining of hardening marten-site in the surface layer, this representing the maximum hardening that it can be reached.

Surface hardening heat treatments are based on laser heating process, sometimes with partial melting, which requires specific surface powers of 10^3... 10^5W/cm^2 and duration of 10^{-2}...1 second.

Through laser heating are achieved the hardening effects of the surface layer of the part, increasing wear and corrosion resistance at ambient temperature and at high temperatures.[4]The variation of hardeness has been studied with a predictive modeling of multi-track laser hardening , resulting that by changing the extent of overlapping of the tracks, it could be controled [2].

Hardening can be achieved by solid state phase transformations (hardening structural) or by quenching from the liquid surface (vitrification); one or other of these alternatives is obtained by laser beam energy distribution with different intensity .

The laser heating, the heating rate to austenitized temperature is high and when the heat source is interrupted, the heat from the surface layer is transmitted to the outside layer and that for the core part with a speed higher than hardening critical speed [3,6]; the superficial layer is auto hardened, structural changes occur without the need for external cooling medium; cooling speed of outer layers heated with laser are higher than 1000 ° C / s. [4].

Thermal cycling of surface hardening by laser radiation is sharp, meaning that heat treatment can proceed without maintenance period at maximum temperature (Fig.1).

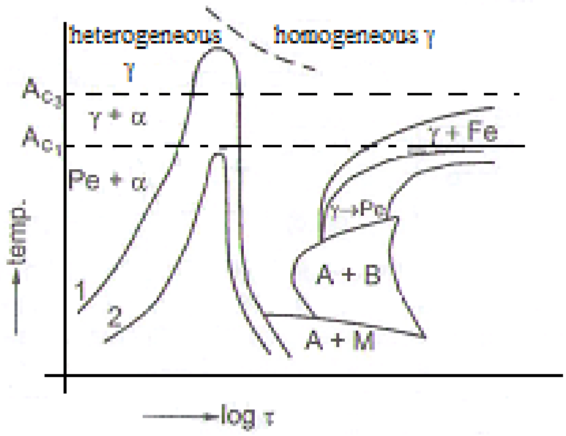


Fig.1. Thermal cycles of laser surface hardening: 1 - on the surface, 2 - at a depth of 0.5mm.

Because of the short action duration of laser radiation, heated layer over Ac_3 gets a homogeneous austenite, with a very fine grain (score 10 ... 11); this austenite is transformed into heterogeneous martensite with an array of charged dislocations. [5]. The keeping of residual austenite is possible because of chemical in homogeneity. Due to these features, hardened layers are characterized by a favorable distribution of compressive internal stress by high toughness, with appropriate hardness, resulting in a final set of qualities that recommended the procedure [6].

2. Hardening parameters of laser radiation

To determine the temperature of laser heated layer is used dimension less temperature criterion.

$$\Theta=\frac{T_k}{T_s}$$

where: T_k-heating temperature for hardening, in K; T_s-current temperature of the surface, in K

The hardening depth on space axis is determined by the relation:

$$\mathrm{ierf{\cdot}c}\left(\frac{Z_k}{2\sqrt{a\cdot\tau}}\right)=\frac{\Theta}{\sqrt{\pi}}=0{,}564\frac{T_k}{T_k}$$

where: Z_k-hardening depth in cm; a – thermal diffusivity steel, in cm^2/s; τ - laser pulse duration, in s.
Maximum temperature after duration of irradiation is situated in the center spot (r =0,Z=0) and has the value:

$$T_s=T_{(0,\tau)}=2\cdot q_s\cdot\sqrt{\frac{a\cdot\tau}{\pi\cdot\lambda}}$$

where: q_s - surface heat flux in W/cm^2; λ - thermal conductivity of steel, in W/m·K
Heating rateat depth Z after time τ is given by:

$$v_{inc}=\frac{q_s\cdot\sqrt{a}}{\lambda\sqrt{\pi\cdot\tau}}\exp\left(\frac{-z^2}{4a\tau}\right)\text{ in K/s.}$$

Considering the case of unidirectional heating of a body half bounded with a surface source of constant intensity, there are expressions of different technological parameters in CO_2 laser irradiation. For this it is introduced the condition that hardening depth reaches the maximum value when surface reaches the hardening temperature, which requires an intensity of heat source:

$$q_{top}=T_{top}\cdot\lambda\left(\frac{\pi}{4ac}\right)\approx 0.393\lambda\cdot v\frac{T_{top}}{a\cdot r}\text{ in W/cm}^2.$$

Duration of heating for hardening will be:

$$t_k=\left(\frac{\pi Z_k^2}{4a}\right)\cdot\frac{T_{top}}{T_{top}-T_k}\approx 0{,}785\frac{Z_k^2}{a}\cdot\frac{T_{top}}{T_{top}-T_k}\text{ in s.}$$

Heating rate will be required:

$$v_{inc}=\frac{8a\sqrt{(T_{top}-T_k)^3}}{\pi\sqrt{T_{top}}\cdot Z_k^2}\approx 2{,}546a\frac{\sqrt{(T_{top}-T_k)^3}}{T_{top}\cdot Z_k^2}\quad\text{in K/s.}$$

And depth of hardening:

$$Z_k=2\sqrt{\frac{a\cdot t}{\pi}}\cdot\frac{T_{top}-T_k}{T_{top}}\approx 1{,}59\sqrt{\frac{a\cdot r}{v}}\cdot\frac{T_{top}-T_k}{T_{top}}\quad\text{in cm.}$$

Effects induced by laser radiation in material part depends on the optical, thermal and mechanical properties of work pieces, intensity and energy of the radiation, the wave length of radiation, radiation structure and the oscillator operating conditions [7,12] .

Metallic materials absorb very well laser radiation with wave length less than 4 μm and the nonmetallic on the wave length greater than 4 μm. [9] At lower power densities occurs the heating material on a depth-dependent of material parameters and pulse duration.[10,11,13]. At power densities over $10^5 W/cm^2$ appears the surface material melting and heating to the interior. If the power density switch $10^{11} W/cm^2$ occurs vaporization, melting and heating, and vapors are in the form of plasma. [5], [14].

There were tested two samples of carbon steel grades 1.0503 (OLC45X) and 1.0601 (OLC60), and two of alloy steel 1.7035 (41Cr4) and respectively 1.6582 (34MoCrNi6), all of the group to improvement steels [8]. Therefore, before surface thermal radiation with laser radiation was carried out heat treatment for improvement, according to Table 1.

Table 1. Heat treatment for improvement applied to steel

Nr. crt.	Steel's type (after SR-EN)	Hardening		Annealing			Hardness [HRC]
		Tempera ture [°C]	Cooling enviroment	Tempera ture [°C]	Duration [h]	Cooling enviroment	
1.	1.0503	840	Water	600	1	Air	32,5
2.	1.0601	830	Water	600	1	Air	37,5
3.	1.7035	840	Oil	600	1	Air	36,5
4.	1.6582	840	Oil	600	1	Air	41

Further samples were subjected to surface hardening by laser CO_2, using the parameters indicated in table 2.

Table 2. Conditions of CO_2 laser surface hardening

P [W]	V [mm/s]	D_{spot} [mm]	D_{beam} [mm]
700/800	7,5	3,5	30

Since the spot diameter generally do not cover the width of the piece take several successive passages. In the tested samples were drawn 5-6 bands. Laser hardened layer microstructures are shown in figure below.

a

b

Fig. 2. Improved steel 1.0503; melted surface; P=800W; Nital attack, 50:1 a - the distance between the spots; b - The partially overlapping spots

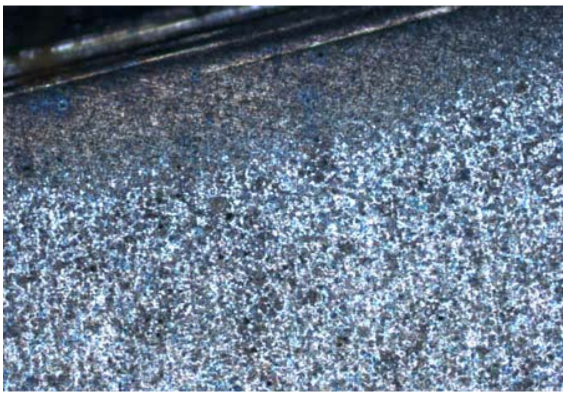
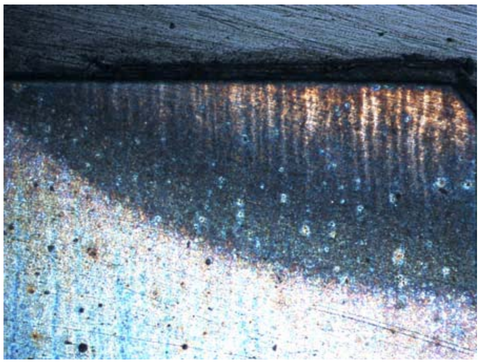
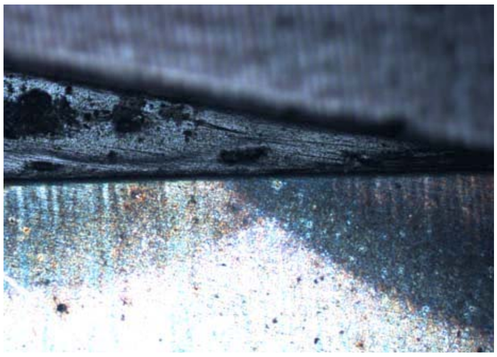


Fig.3. Steel 1.0601 improved and surface hardened with CO_2 laser; P=700W; Nital attack; 200:1

Fig.4. Steel 1.0601 improved and surface melted with CO_2 laser; P=800W; Nital attack; 200:1



a



b

Fig.5. Steel1.6582 improved and surface hardened with CO_2 laser; P=700W; Nital attack; 200:1 a - depth Z of the layer, b - spots partially overlapped.

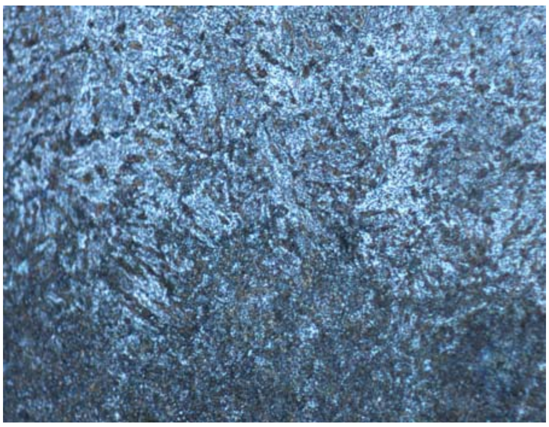


Fig.6. Steel 1.6582 improved and surface hardened with CO_2 laser; P=700W; Nital attack; 500:1. Crossing area between hardened layer and core

Hardened surface layer hardness was measured using a Vickers microdurometer. In Table 3 are given maximum hardness values obtained.

Table 3. The hardness of surface steels

Vickers Hardness [HRC]			
1.0503Steel	1.0601Steel	1.7035Steel	1.6582Steel
61	64,5	56	57

A feature of hardened surface layers by laser and obtained through multipass is the hardness variation between maximum and minimum values, hardness measured by a vertical direction on the tape hardened. The diagram obtained from these measurements looks sinusoidal, as in Fig. 7. This application is preserved both for distant spots, as in that of partially overlapping spots.

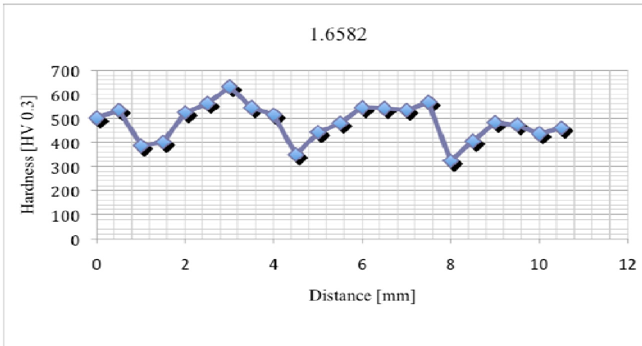
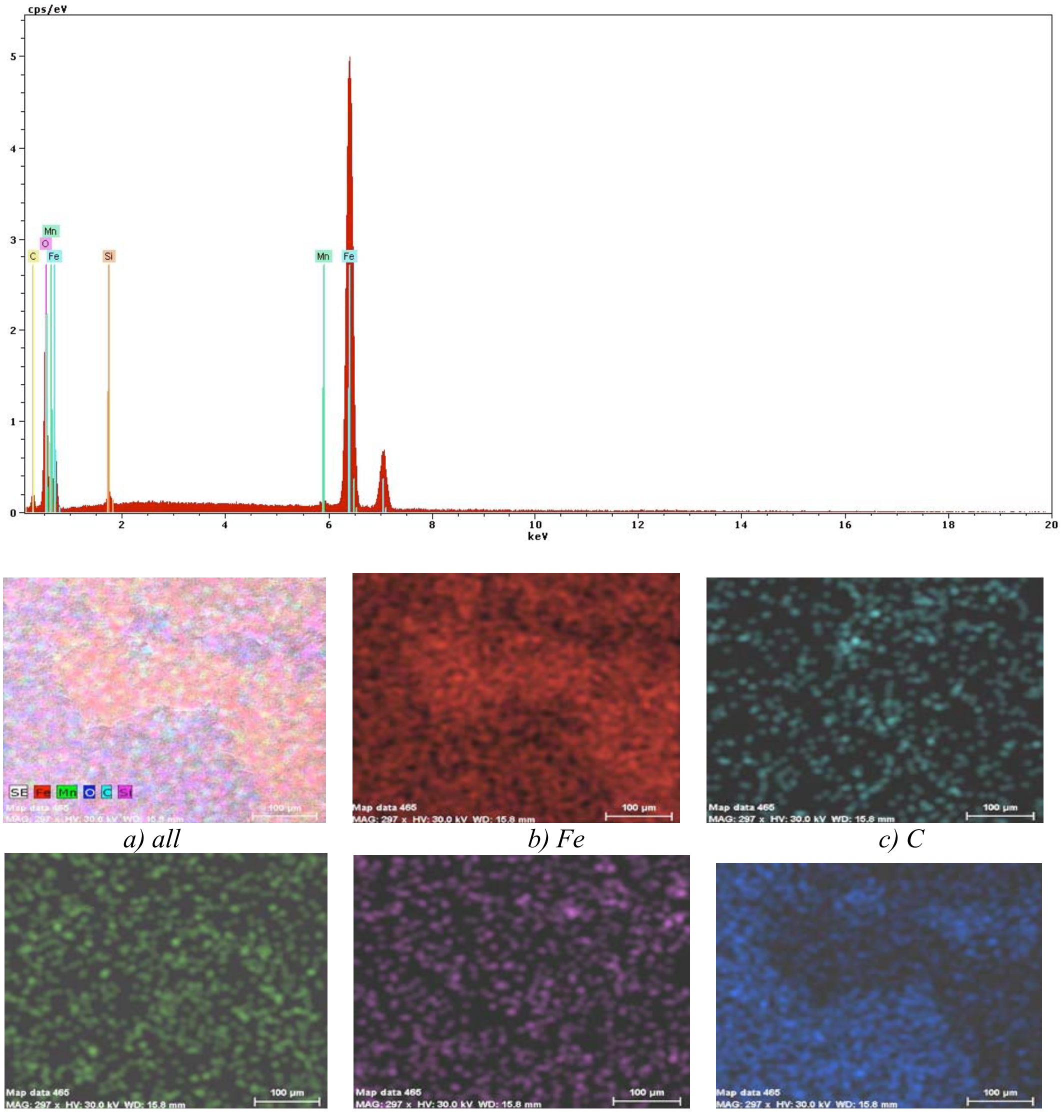


Fig.7. Steel 1.6582 improved and surface hardened with laser; P =700W; Vickers hardness(HV_{03}) measured perpendicular to the spot.

Analysis performed by X-ray spectrometry, respectively SEM and EDAX highlight existing elements in the hardened superficial layer, their distribution and microstructure, as shown below.



a) all *b) Fe* *c) C*

d) Mn *e) Si* *f) O*

Fig. 8. Steel 1.0305 improved and surface hardened with laser. EDAX analysis with X-ray fluorescence spectrometer.

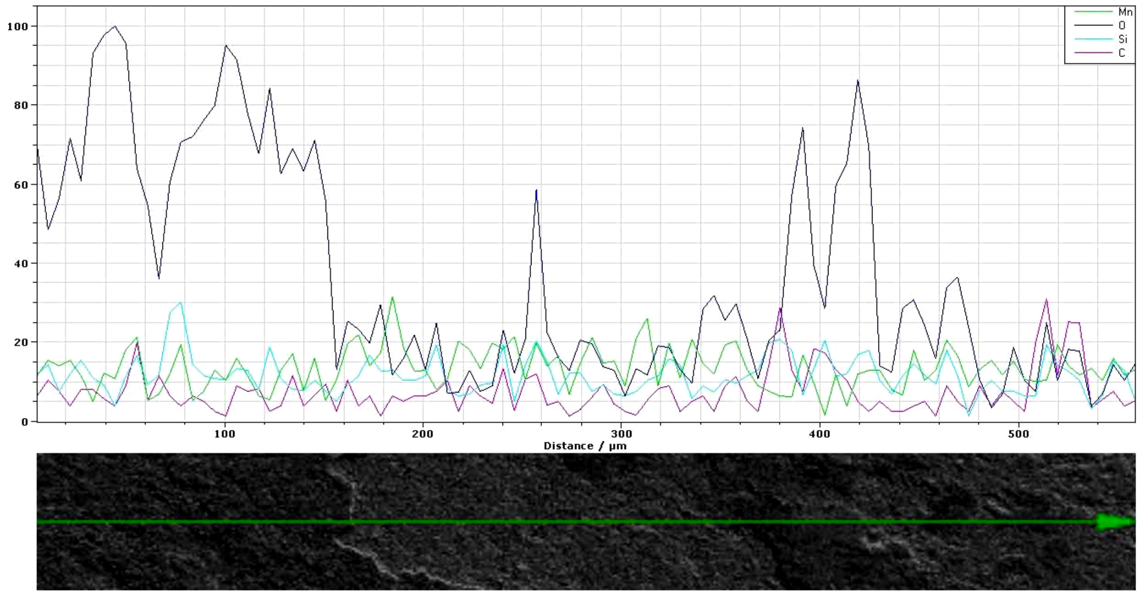


Fig. 9. Steel 1.0305 improved and surface hardened with laser. Micrographs SEM+EDAX with identified elements in layer microstructure and their graphical representation.

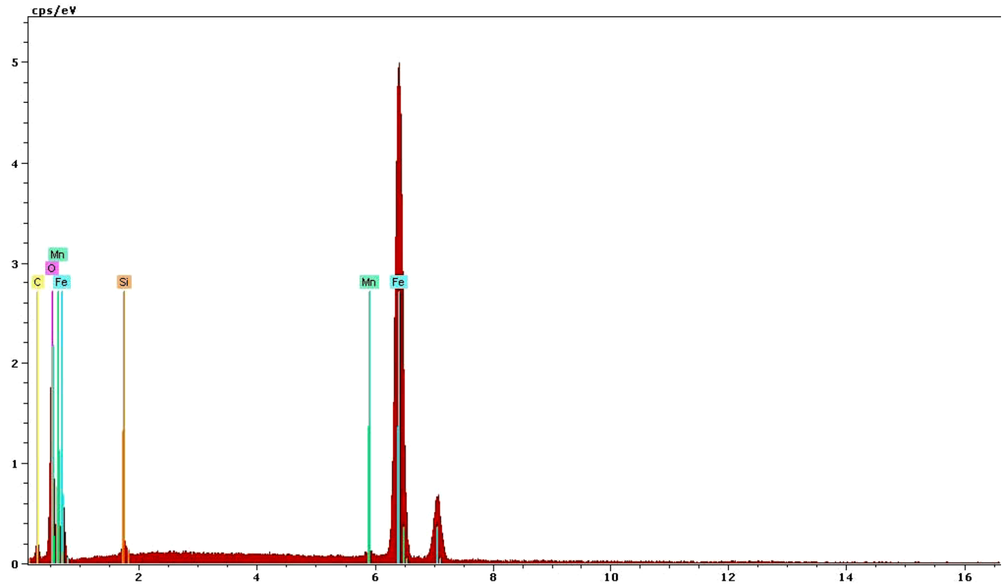


Fig. 10. Steel1.0305 improved and laser surface melting. X-ray diffraction.

3. Discussion

Conditions of development for heat treatment of improvement applied to steel are shown in table1. The specimens tested were fabricated of carbon steel grades 1.0503 (OLC45X) and 1.0601 (OLC60), and of alloy steel 1.7035 (41Cr4) and respectively 1.6582 (34MoCrNi6). Furthermore table 1 contains the hardeness values after hardening and annealing of studied steels.

Adjacency or the overtaking trough the specific surface power used of critical flow at the melting beginning causes a surface layer characterized by melting and rapid cooling, facilitating the emergence of dendritic structures and residual austenite, resulting in a appreciable hardness. Modify the structure of hardened layer by the appearance of mass transfer processes by partial melting laser, resulting in changes in chemical composition. This is emphasized in the images of micrographs of 1.0503 steel (OLC45X) obtained with optical microscope (OM) in Fig. 2. By comparing the images of micrographs of 1.0601 steel (OLC60) in figures 3 and 4 it can be seen the difference in surface structure of a hardened surface (Fig. 3) with CO_2 laser working parameters of P = 700W, and a melted surface (fig. 4) with CO_2 laser working parameters of P = 800W, on the same treatable steel, which was previously subject to heat treatment to improvement.

Trough superficial treatment of the surface with ultra-fast heating under external concentrated heat sources by high specific capacity, there has been acquired different hardness recorded on specimen layer. Thus as it can be seen in figure 7, microhardness variation depends on the hardening area, with maximum microhardness in the largest deep spot of 632 ($HV_{0,3}$) and in the area where there is partial overlap of the spot over previously hardened zone lower values, such as for example 324 ($HV_{0,3}$) .

Images that are achieved with optical microscopy (OM) are shown in figure 5. The structure of surface layer (specimen of 16582 steel), was obtained after hardening with CO_2 laser, characterized by following technological parameters: P = 700W; d_{spot} = 3.5 mm; d_{beam}= 3 mm, v = 7.5 mm / s. In the micro area of interest is could be destinguished in a) spot dimension with maximum depth and in b) partially overlapping spots. Furthermore it is noticed the zone of thermal influence, (HAZ).

In Fig. 6 presents images of micrography structure in the layer depth for steel 1.6582 (34MoCrNi6) after surface hardening with laser radiation. It reveals the crossing area between the hardened layer and core.

From metallographic analysis were observed the obtaining in the surface layer of a martensitic structure and the core preserving the annealing sorbite. This was possible given the fact that working temperature is a higher one superior to austenite temperature without reaching the melting temperature of the material, point confirmed in the literature.

4. Conclusions

Laser energy can be used for superficial heat treatments of carbon and alloyed improvement steels.

Hardened surface layers get comparable hardness to those obtained by classical methods or even higher. Laser hardening presents the advantages:

- Very short duration of the process;
- No external cooling medium (water, oil);

Hardening can be achieved through structural transformation in solid or by surface melting.

In the case of own attempts it has achieved the surface hardening by both mechanisms, modifying the laser radiation power:

- The laser radiation effect is local, heating followed by rapid cooling is not affected adjacent area or they are influenced to a small extent;
- Can be hardened in small areas, impossible by other methods.

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