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Increasing of the superficial hardness of a coupling system realized from a low carbon steel ST37-2 by surface treatment with Nd:YAG laser

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This paper presents a study of the hardening effects on a coupling system realized from a low carbon steel ST37-2 by applying a laser surface treatment, on a well defined zone. The paper aim is to approach a technological point of view regarding the possibility of a superficial local hardening on hydraulic coupling system made from ST37-2 mild steel. 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 700 µm. The optimal values of the laser processing treatment have been obtained by the theoretical calculation of the cooling velocity in temperature domain of 800^{o}C and 500^{o}C.

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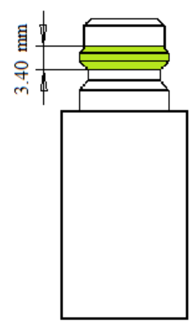
Keywords: Heat treatment, Nd:YAG laser, Surface heat treatment, Push-in coupling system, ST37-2

1. Introduction

The aim of this paper is to approach a technological point of view regarding the possibility of a superficial local hardening on hydraulic coupling system made of ST37-2 mild steel. Mechanical coupling systems utilized for couplers push-in have a localized zone that is exposed to wear during compression, due to the pressure exercised by the opposite components (balls) in the specific area (Fig. 1). In order to improve the properties and characteristics of this zone it was performed a heat treatment with Nd:YAG laser (λ=1064 nm) on a very tight area where the coupling's mechanical stress occurs. The Laser surface treatment has been applied to a small and localized area, and is due to the fact that the energy supplied by laser beam is absorbed by the base material and converted into thermal energy, leading to zonal heating and melting of metallic component [1, 2]. After rapid cooling of the heat affected area there is a possibility to obtain hardened microstructures, as result of phase transformation following cooling phase nonequilibrium, with characteristics of high hardness and consequently, higher wear resistance.

Laser surface heat treatment presents a particular interest today because it allows reconstructing features from strategic materials or improving characteristics of hardness and wear resistance [3- 5]. Due to its high costs of processing application of laser surface treatment at an industrial scale is limited to special applications, for which the precision of intervention and dozage of heat input must be kept within very tight limits.



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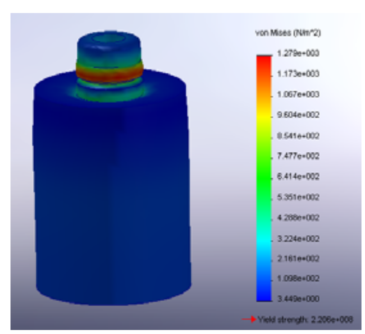


b

Fig. 1. Area of interest on the coupling system a) diamensioned and b) in a simulation program.

It is very important to keep a very precise dosage and a well control on the heating of material during laser surface treatment, at a temperature above the transformation temperature, without reaching the metal's melting point [6-9].

2. Theoretical consideration

In the specific analyzed case it is necessary to estimate the depth at which occurs phase transformation with an effect of increased hardness. To estimate the penetration depth, some formulas that allow to calculating the depth of treated zone as a function of the cooling rate value in the temperature range 800 to 500^{o}C and the input laser energy. In the case of laser surface treatment the relation for bi-dimensional propagation of heat can be used, from which it can be derived the penetration depth of treated area, by calculating the cooling time $t_{8/5}$ [13]:

$$t_{8/5} = (4300 - 4{,}3 \cdot T_0) \cdot 10^5 \cdot \frac{Q^2}{d^2} \cdot \left[\left(\frac{1}{500 - T_0} \right)^2 - \left(\frac{1}{800 - T_0} \right)^2 \right] \cdot F_2 \quad (1)$$

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) [16]
Q = input energy [kJ/mm]

In the case of steels, the effect of hardness change as an effect of phase transformation is estimated using the cooling time between 800 and 500^{o}C [9,10]. To determine the optimum values of the regime parameters for Nd:YAG laser surface treatment, different values of penetration depth have been calculated using a constant value for $t_{8/5}$ = 0.28s, a constant value of laser beam diameter of 1mm, the initial temperature of the base material was T_0 = 17 ^{o}C and different values for input energy were used: 4,2 ; 6,3 ; 8,41 ; 10,51 and 12,61 kw/cm^2 for steel ST37-2.

3. Experimental procedure

In order to study the effects of laser surface treatment (such as good corrosion resistance, wear resistance, increased hardness, etc.) 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 2 – 6 mm/s) and a constant value of laser spot diameter (1mm) (Fig. 2).

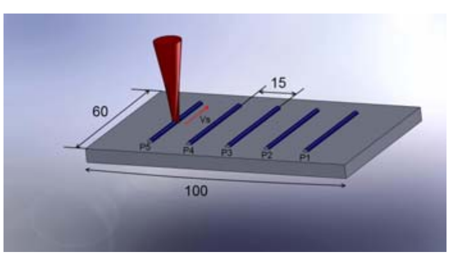


Fig. 2. Process diagram of laser surface treatment.

Table 2. Chemical composition of low carbon steel ST37-2 DIN 17100.

Chemical elements	C≤ 16mm max	C>16mm 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 the effects of phase transformations that may appear during the heat processing [14-21].

The cleaning of parts surfaces that undertake the laser heat treatment must be performed with extreme care, in order to ensure the removing of impurities such as dust, paint, grease, traces of water, etc., that may lead to formation of numerous defects such as craters, oxidation of the surface, porosities, and cracks [22,23].

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: material base - MB, heat affected zone -HAZ and treated zone –TZ (Fig. 3). 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 HV_1. The penetration depths of the zones that was heat treated with laser were measured by the optical macroscopy (Fig. 3), using an Olympus GX51 optic microscope equipped with image analysys software AnalySis.

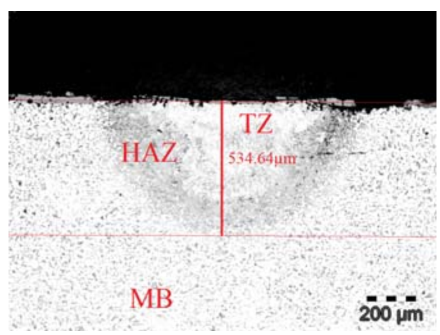


Fig. 3. Macroscopic analysis of an area treated with Nd:YAG laser, power density 8.41 kW/cm^2, 100x magnitude.

4. Results

After analyzing the experimental data it was found that even for values of power density that are under 4.2 kW/cm^2 for all laser speeds used, it was obtained a heat treated area and a heat affected zone (Fig. 4b).

When applying a higher power density of 4.2 kW/cm^2 in the microstructure it was obtained 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) (Fig. 4a and 4b).

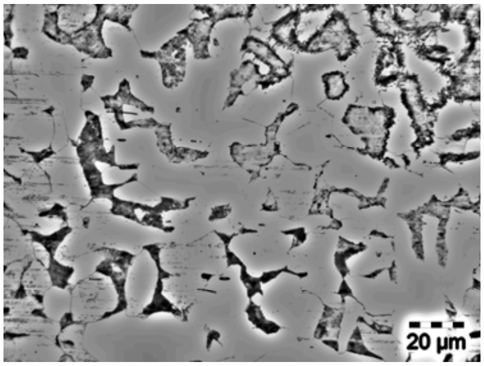


Fig. 4. Granular structure of the base material.

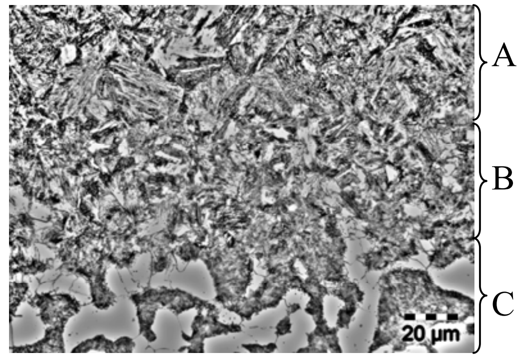
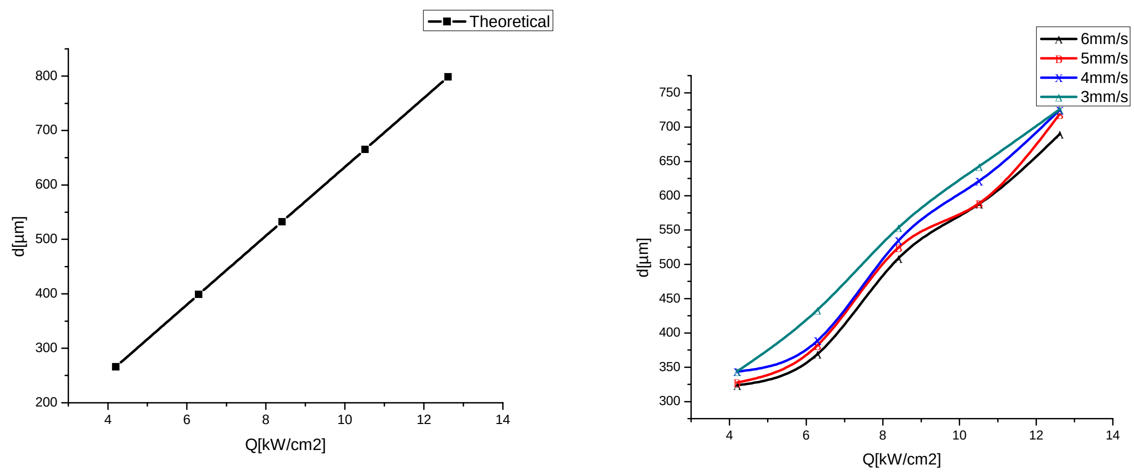


Fig. 4b. Granular structure of the material (A – fine grains in the thermal treatment zone, B – transition zone or heat affected zone – HAZ and C – base material).

Using the optical microscopy it was possible to measure the penetration depth resulting from the application of laser heat treatment. A comparison of its effects on the treated zone could be done, using rel. 1 are presented in Fig. 5a and 5b.



a b

Fig. 5. Evolution of penetrations depth: a) calculated values; b) measured values as function of laser energy during laser surface treatment for different values of speed.

It has been observed that for a constant value of 0,28s for $t_{8/5}$ the theoretical depth varies linearly with laser beam power, while in the experimental model appears an exponential variation (rel.2) with limits of variation positioned near to the theoretical curve.

$$Y = 0.000262 + 8.804755 \cdot x \qquad (2)$$

Where Y = the depth of the treated area [mm]

x = input energy [kJ/mm]

After measuring the microhardness of the treated areas, it was found that the average values of microhardness are as follows: near surface 350 HV_1, in the centre of the treated area 410 HV_1, in the root 500 HV_1, on the right side of HAZ 212 H_1 and on the left side of HAZ 195 HV_1 (Fig. 6).

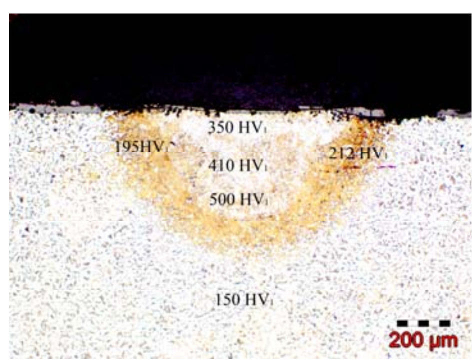


Fig. 6. Average values of microhardness in the treated area.

The evolution of the average values of hardness depending on the depth of penetration is presented in Fig. 7.

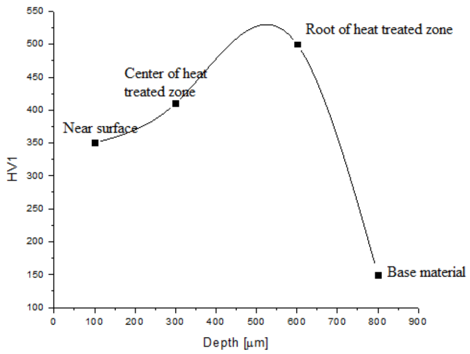


Fig. 7. Hardness evolution depending on the depth of penetration.

The best results were obtained for values of displacement speed of the laser beam between 4mm/s and 3mm/s, for which were obtained penetration depths up to 600-700µm and a change of crystalline microstructure of the material. 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 500 HV_1.

This is caused by the fact that increasing the heat quantity in the treatment zone the effective cooling rate is reduced [18], a factor that is determinant for martensite formation.

By increasing the speed of the laser radiation a reduction in microhardness is observed, caused by the fact that superior moving speeds don't allow the necessary heat quantity to be delivered to the base material inhibiting martensite formation, in sufficient quantity or at all.

At the same time, it may be observed that increasing the power density, an increase in the depth of the heat treated zone is attained (Fig. 8), while by increasing the moving speed of the laser beam reduces the depth.

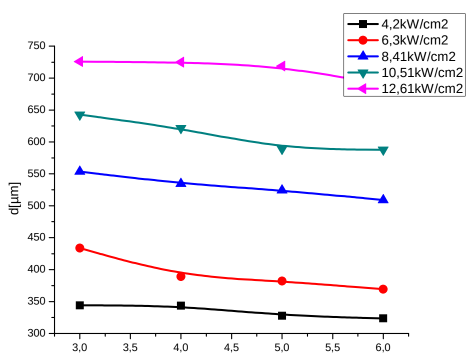


Fig. 8. Variation of heat treated zone depth depending on laser beam speed and power density.

Analyzing the results of this study, it may be concluded that for ST37-2 steel, the best process parameters for laser surface heat treatment are at a power density of 6,3 kW/cm2 and a speed of 3mm/s, presenting a high value of microhardness and a larger penetration depth.

Starting from these parameter values, a surface laser heat treatment process has been applied for an industrial application, in which the laser system was in fix position and the analyzed part (the coupling system) was rotated using an electric positioning device, for realizing the treatment on the circumference.

In this configuration a thin heat treatment zone was generated on the circumference, which was later analyzed by optical microscopy and microhardness measurement (Fig. 9). The heat treated component is a coupling system, in which the mechanical stress zones were analyzed in cross section, in order to determine the microhardness values, measurement of heat treated zone depth and microstructure transformations estimation.

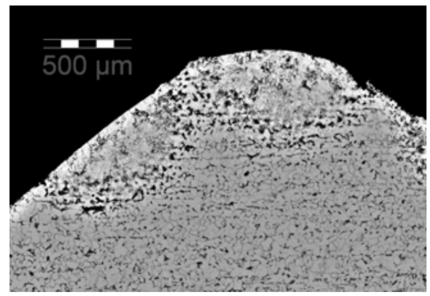
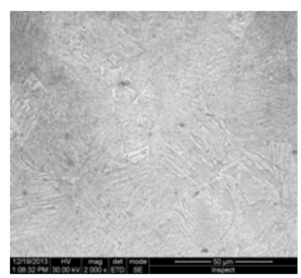


Fig. 9. The transversal section of laser heat treated zone, using a power density of 6.3 kW/cm^2.

The metalographic analysis of the laser heat treated zone revealed a microstructure formed from martensite and residual austenite in the zone of full phase transformation, and needle-like ferite in the zones of transition to the base material (Fig. 10).



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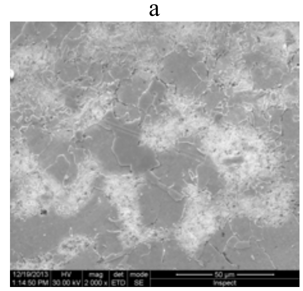

b

Fig. 10. Microstructure of the laser heat treated zone using power density of 6.3 kW/cm^2 and rotations speed of 27˚/sec a) in the heat treated zone and b) in the heat affected zone.

5. Conclusions

The experimental researches on ST37-2 steel with Nd:YAG laser showed that superficial hardening of cylindrical surfaces is possible using laser radiation, for coupling systems made from this type of material. The research has allowed the determination of the optimal process values, respectively: speed and power required to treat de interest zone on coupling system. The maximum hardness values were obtained for power density of 6.3kW/cm2 and moving speed of 3mm/s.

By increasing the speed rotation of the component, thus increasing the speed of the laser beam in rapport with the surface, a significant decrease in the penetration depth of heat treated zone is produced (from maximum value of 700μm to 300 μm) confirming the experimental study (Fig. 9).

At the same time, increasing power density of the laser beam determine an increase in the depth of the heat treated zone. This confirms the theoretical estimation (Fig. 5a) and the experimental studies (Fig. 9).

The results offer an encouraging perspective regarding the use of this kind of low carbon steel 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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References

[1] W. Steen, Laser material processing, ed. Springer, 1998.
[2] L. Migliore, Laser Material Processing,ed. M. Dekker, 1996.
[3] J. F. Ready, Industrial Application Of Laser, ed. Academic Press, 1997.
[4] O. Dontu–Tehnologii de prelucrare cu laser, Editura Tehnica, Bucuresti, 1986.
[5] O. Dontu s.a. –Buletinul IPB, seria Mecanica, Tom XLVII-1984.
[6] V. Geanta, I. Voiculescu, R. Ştefanoiu, D. Savastru, D. Daisa, J. Optoelectron. Adv. Mater. **15**, (11-12), 1457 (2013).
[7] M. Cazacu, A. Zara, M. Stoicanescu, I. Giacomelli , J. Optoelectron. Adv. Mater. **15**(9), 1125 (2013).
[8] L. A. Dobrzański, J. Domagała, T. Tański, A. Klimpel, D. Janicki, Journal of Achievements in Material and Manufacturing Engineering, **28**(2), 179 (2008).
[9] D. Savastru, D. Tenciu, C.P. Lungu, M. Osiac, C. Viespe, C. Grigoriu, R. Iordanescu, I. D. Feraru, V. Ionescu, O. Monnereau, L. Tortet, R. Notonier, C. E. A. Grigorescu, Digest Journal of Nanomaterials and Biostructures, **6**(1), 2007 (2011).
[10] M. Ciobanu, C. Nicolicesu, I. G. Bucse, I. Stefan, J. Optoelectron. Adv. Mater. **15**(7), 797 (2013).
[11] V. Geanta, I. Voiculescu, R. Ştefanoiu, D. Savastru, I. Csaki, D. Patroi, L. Leonat, Optoelectron. Adv. Mater. Rapid Comm. **7**(11-12), 874 (2013).
[12] M. Heitkemper, A. Fischer, Ch. Bohne, A. Pyzalla, 6th International Tooling Conference, 935 (2013).
[13] ASM Handbook **6**, 34 (2001).
[14] R. K. Nalla, I. Altenberger, U. Noster, G. Y. Liu, B. Scholtes, R. O. Ritchie, Materials Science and Engineering **A355**, 216 (2003).
[15] Khansaa Dawood Salman, Eng. & Tech. Journal, **27**(6), (2009).
[16] M. Morales, J. Torres, C. Molpeceres, J. A. Porro, J. L. Ocana, LANE Laser Assisted Net Shape Engineering, **4**, 885 (2004).
[17] J. L. Ocaña, D. Iordachescu, M. Blasco, M. Iordachescu, Metalurgia International., **14**(10), 10 (2009).
[18] O. Monnereau, L. Tortet, C. E. A. Grigorescu, D. Savastru, C. R. Iordanescu, F. Guinneton, R. Notonier, A. Tonetto, T. Zhang, I. N. Mihailescu, D. Stanoi, H. J. Trodahl, J. Optoelectron. Adv. Mater., **12**(8), 1752 (2010).
[19] V. Miclosi, Editura Sudura, Timişoara, 2003.
[20] Zhenqing Zhao, Chunqing Wang, Mingyu Li, Lei Wang, Surface&Coatings Technology **200**, 2181 (2005).
[21] M. I. Rusu, R. Savastru, D. Savastru, D. Tenciu, C. R. Iordanescu, I. D. Feraru, C. N. Zoita, R. Notonier, A. Tonetto, C. Chassigneux, O. Monnereau, L. Tortet, C. E. A. Grigorescu, Applied Surface Science, **284**, 950 (2013) http://dx.doi.org/ 10.1016 / j.apsusc.2013.04.061.
[22] I. Voiculescu, V. Geanta, R. Stefanoiu, H. Binchiciu, Sudura, Vol **XXI**-4/2011 Chisinau, Moldova.
[23] C. P. Lungu, C. E. A. Grigorescu, I. Jepu, C. Porosnicu, A. M. Lungu, D. Savastru, I. D. Feraru, Diamond and Related Materials, **20**, 1061 (2011), (DOI information: 10.1016/ j.diamond. 2011. 06. 010).
[24] C. R. Iordanescu, D. Tenciu, I. D. Feraru, A. Kiss, M. Bercu, D. Savastru, R. Notonier, C.E.A. Grigorescu, Digest Journal of Nanomaterials and Biostructures, **6**(2), 863 (2011).
[25] M. I. Rusu, R. Zamfir, E. Ristici, D. Savastru, C. Talianu, S. Zamfir, A. Molagic, C. Cotrut, J. Optoelectron. Adv. Mater. **8**(1), 230 (2006).

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