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SUPERFICIAL HARDENING WITH PULSE LASER APPLIED TO ASTM A537 HSLA STEEL

Nelu CAZACU, Bogdan Silviu VRABIE
"Dunarea de Jos" University of Galati
e-mail: nelu.cazacu@ugal.ro, vrabie.bogdan10@gmail.com

ABSTRACT

The surface hardening with YAG:Nd pulse laser is used to obtain a set of surfaces with different properties and it is based on the formation of a very fine martensite.

The paper has been elaborated based on laboratory experiments on samples of A537 (HSLA steel).

KEYWORDS: pulse laser, YAG:Nd, hardening, surface treatment

1. Introduction

Laser hardening (LH) became an important technology to obtain superficial coatings with high hardness, which could increase the utilization time of some parts [1], due to the possibility to concentrate the energy on controlled surfaces and thus to obtain high density energies.

The details of the factors are shown in Fig. 1:

Fig. 1. *Factors influencing the LH process*

In steels:

• laser hardening leads to the formation of very fine martensite;

• nitrocarburizings in fluidized bed is an effective method.

The interaction of laser radiation with a solid is an important point of concern, initially in theory [2] and lately with technological applications [3].

Notations and Abbreviations
HSLA steel – High Strengh Low Alloy
LH - Laser Hardening,
SE – Surface Engineering,
YAG:Nd – Yttrium Aluminum Garnet, Neodimoium doped

A sum of elementary processes is conducted at very high speed leading to the reorganization of atoms in a solid substance in response to the excitation energy for short periods of time. The energy of the laser radiation and high heating and cooling rates result in substantial changes in the structure and material properties of the surface layer. Within certain limits and under adequate control of the influencing factors, [2], this interaction may be useful in SE technological applications.

2. Experimental

2.1. Equipment

For the experiments we used the equipment existing in the laboratories of the Faculty of Metallurgy and Materials Science, *Dunarea de Jos* University of Galati. Pulse Laser installation KVANT 17 (YAG: Nd) is a facility dedicated to welding and cutting materials where these operations are difficult to achieve with other methods or other methods are not available.

Fig. 2. *YAG laser system image: pulsed Nd (KVANT 17)*

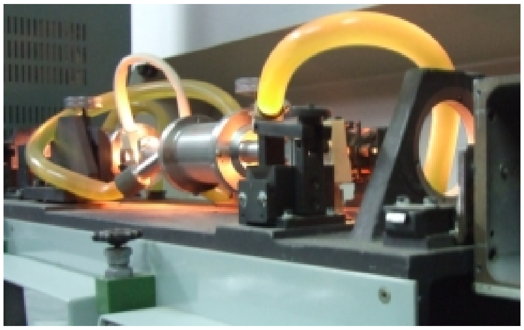

Fig. 3. *YAG laser system image: pulsed Nd (KVANT 17)*

The main features of the system are: active medium solid glass Y3Al5O12 (yttrium aluminum garnet) laser glass size: 6.3 mm 100 mm diameter, 1.06 µm wavelength (IR) pulse duration 2 ... 5 ms 1 ... 20 Hz operating frequency. Object focal distance 50 mm equivalent at maximum focalization diameter 0.3 ... 1.3 mm, pulse energy min. 8J, scanning surface 400 mm^2 (20 mm x 20 mm), 2 functional units simultaneously.

Fig. 4. *Interaction of laser radiation with sample and intense sparks due to interaction*

2.2. Samples

For the experiments we have used A537 steel samples characterized by:
- material: A537 (normalized condition);
- shape: disc two sides prepared;
- size 27 mm x 44 mm x 12.38 mm;
- initial properties;
- status of the surface.

Deviations from sample to sample should be minimal.

The experiments were carried out taking into account the following factors of influence cumulated for all technological operations. Depending on previous experience, there is a hierarchy of factors influencing the light of the objective function (out).

Table 1. *Chemical compositions of A537 –ASTM A537(HSLA steel)*

Element	Width, mas %		comments
	on liquid	on solid	
Carbon	max. 0.24	max. 0.24	
Mangan	0.70 … 1.35	0.64 … 1.46	< 40 mm width
	1.00 … 1.60	0.92 … 1.72	> 40 mm width
Phosfor	max. 0.035	max. 0.035	
Sulf	max. 0.035	max. 0.035	
Siliciu	0.15 … 0.50	0.13 … 0.55	
Copper	max. 0.35	max. 0.38	
Nichel	max.0.25	max. 0.28	
Cromium	max. 0.25	max. 0.29	
Molibdenium	max. 0.08	max. 0.09	

Table 2. *Properties of the steel according to the state of A537 heat treatment (ASTM)*

Grade	Heat treatment	Width	Yield (min)	Tensile strength (min)
u.m.	-	mm	Mpa	Mpa
1	Annealing	< 65	345	485
		65 … 100	310	450
2	quenching and tempering	< 65	415	550
		65 … 100	380	515
		100 … 150	315	485
3	quenching and tempering	< 65	380	550
		65 … 100	345	515
		100 … 150	275	485

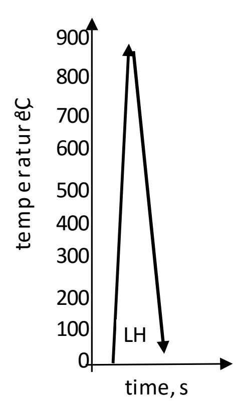

Fig. 5. *Cycle quenching and tempering heat treatment applied to the A537 steel*

2.3. Testing regimes

The matrix experiment has to take into account these factors and their hierarchy, even if a procedure is not yet developed for determining the weight factors on the process quality and regimes. The steel used is part of HSLA steel. The initial state of the material is normalized condition (delivery).

3. Results and discussions

The investigations highlighted changes in structure, properties and performance.

The macroscopic analysis serves to highlight the changes in the surface morphology of the treated samples. Pictures of the surface morphology are mainly about the different regimes LH laser activation and morphological changes (craters, waves, scales, modes of vibration, uneven heating, etc.). In Fig. 6 are presented the samples after LH and in Fig. 7, are presented the same samples after FBNC. These samples present in the end a dark gray coloration. To allow the hardness tests, a superficial polishing was realized using fine abrasive paper (>1200).

Optical microscopy (metallographic) highlights superficial changes, knowing that treated surfaces have a specific texture due to the interaction laser / material.

Usually, the samples surface must be processed uniformly and continuously implying an overlap of 10 ... 30% of traces for each interaction (Fig. 5). An increase in the intensity of the laser spot and a reduction of defocus have the effect of increasing the depth and reduce surface traces. The presence of a strong local melting (Fig. 8) leads to local hardening mechanism by recrystallization at high speed.

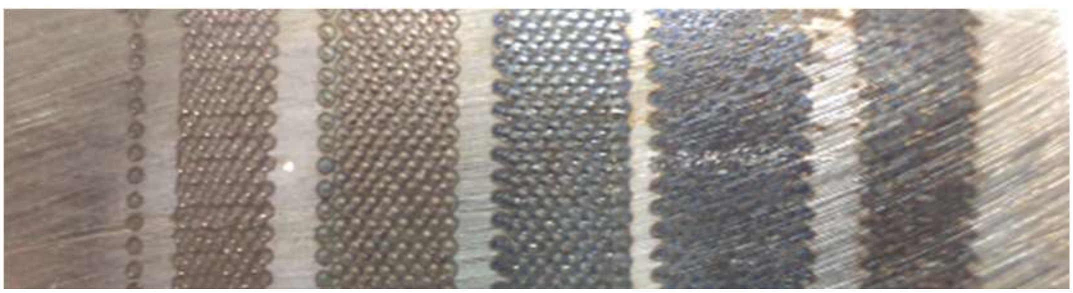

Fig. 6. *Image of the area after LH*

This hardening mechanism is present in most samples (Figs. 8-14).

Hardening by local quenching is shown in Fig. 13 and partially in Fig. 14. The staining surface in the presence of oxygen in the air is dependent on surface temperature obtained after interaction with the focused spot of laser radiation. At a macroscopic scale, average surface hardness is obtained, as a weighted average of local hardness obtained by one of two mechanisms.

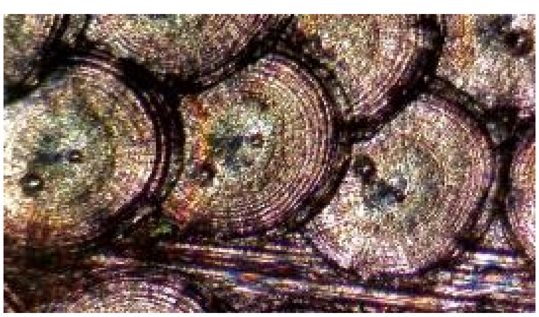

Fig. 7. *LH sample after the 1a regime (length of the image corresponds to 1.2 mm)*

Fine martensite formations and possible fine dispersion of hard nitride precipitates are highlighted.

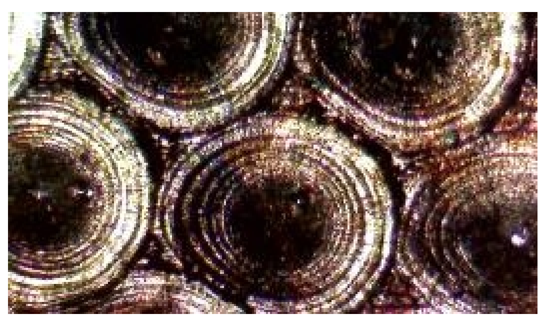

Fig. 8. *LH sample after the 2b regime (length of the image corresponds to 1.2 mm)*

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***Fig. 9.** LH sample after the 3a regime (length of the image corresponds to 1.2 mm)*

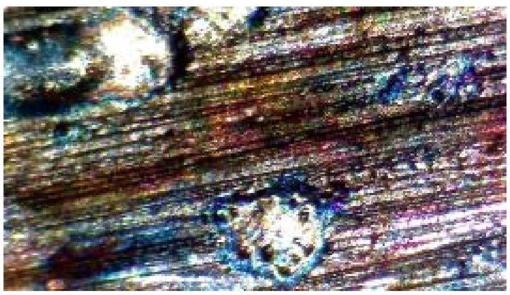

***Fig. 10.** LH sample after the 4a regime (length of the image corresponds to 1.2 mm)*

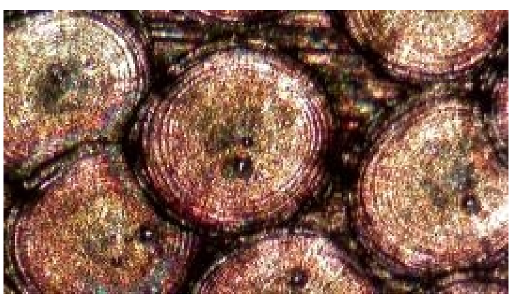

***Fig. 11.** LH sample after the 5a regime (length of the image corresponds to 1.2 mm)*

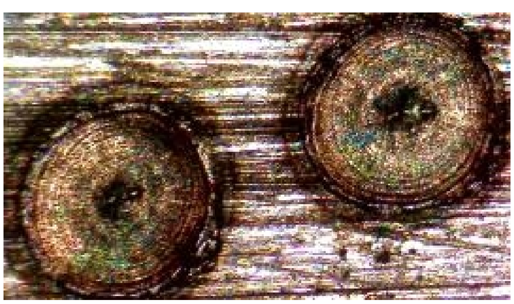

***Fig. 12.** LH sample after the 6b regime (length of the image corresponds to 1.2 mm)*

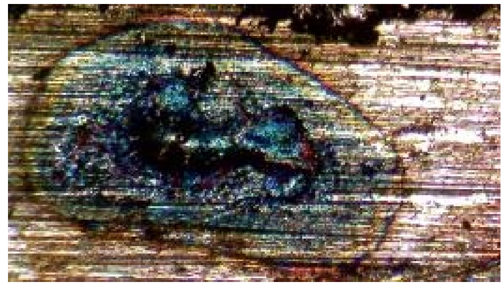

***Fig. 13.** LH sample after the 7a regime (length of the image corresponds to 1.2 mm)*

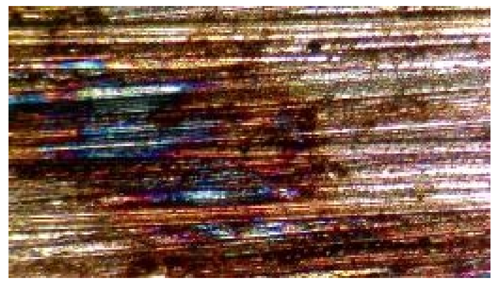

***Fig. 14.** LH sample after the 8a regime (length of the image corresponds to 1.2 mm)*

3.1. Surface hardness

Surface hardness is the main technological feature being measured and obtaining a high hardness is a condition to reduce the wear of treated metallic materials.

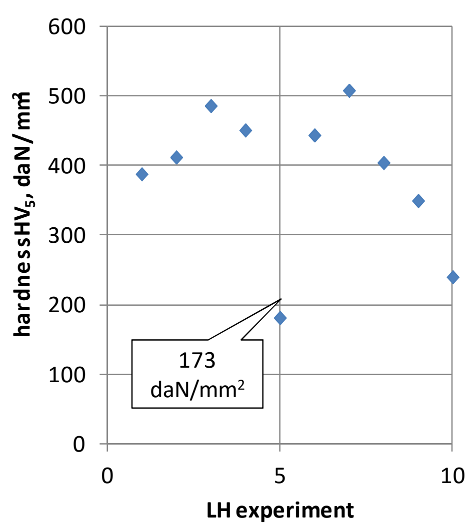

***Fig. 15.** Variation of hardness over surface of A537 steel samples after laser hardening (LH)*

Table 3. *Experimental matrix for A537 laser hardening (LH)*

experiment	Ox steps	puls	delay	defocalisation	mean Hardness HV_5	Battery voltage
m.u.	-	-	s	mm	daN/mm^2	V
1	1	1	1	0	387	1000
2	1	1	1	2.5	411	1000
3	1	1	1	5	485	1000
4	1	1	1	7.5	450	1000
5	1	1	1	9	181	1000
6	4	1	1	9	443	1000
7	4	1	1	7.5	507	1000
8	4	1	1	5	403	1000
9	4	1	1	2.5	349	1000
10	4	1	1	0	239	1000

Tabel 4. *HVD in surface hardness daN/mm^2 laser hardened samples A537*

experiment no.	d_1	d_2	d_3	HV_5 (1)	HV_5 (2)	HV_5 (3)	HV5 med	observations
m.u.	mm	mm	mm	daN/mm^2	daN/mm^2	daN/mm^2	daN/mm^2	-
0	0.231	0.232	0.231	174	172	174	173	initial hardness (after annealing)
1	0.185	0.140	0.149	271	473	418	387	
2	0.149	0.189	0.129	418	260	557	411	
3	0.150	0.145	0.124	412	441	603	485	
4	0.109	0.190	0.172	780	257	313	450	
5	0.230	0.230	0.220	175	175	192	181	
6	0.148	0.150	0.137	423	412	494	443	
7	0.128	0.135	0.144	566	509	447	507	
8	0.129	0.168	0.169	557	329	325	403	
9	0.174	0.145	0.176	306	441	299	349	
10	0.209	0.184	0.200	212	274	232	239	

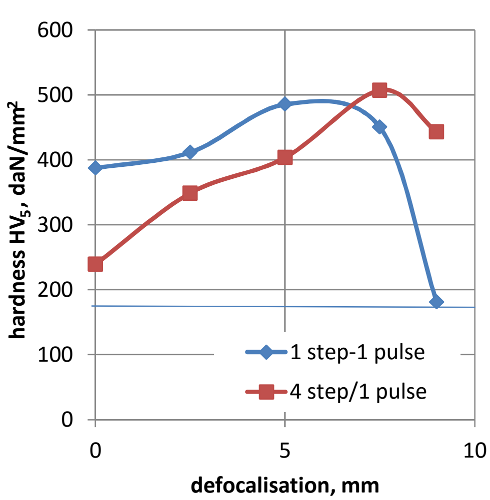

Fig. 16. *Defocusing influence over surface Hardness of A537 steel samples after LH*

3.2. Microhardness in section

Getting a slow transition structure and properties is a condition that is not beyond the breaking strain layer and produces exfoliation. Checking the property of the superficial layer is done by the Knoop or the Vickers microhardness tests.

Microhardness variation can be correlated with treatment regimes.

4. Conclusions

1. The hardness after treatment is higher than the initial hardness (173 daN/mm^2) of samples for all experiments (Fig. 15). Changing the superficial hardness shows that interactions between laser radiation processes and the sample surface (steel A537) were present in all regimes.

2. Changing the setting levels for influence factors (number of successive steps, defocus the laser spot, etc.) leads to changing the surface topology (Fig. 8 ... Fig. 14) and surface properties (hardness).

3. Changing the number of successive steps to a pulse, has the effect of altering the final hardness (Fig. 16) by changing the heat exchange with the substrate material. Using distant pulses results in a higher final hardness (up to 507 daN/mm^2). The phenomenon is due to the thermal diffusivity of the material that allows better cooling after an interaction, and thus to a better subcooling for martensitic transformation or recrystallization.

4. Differences between experimental regimes are found in a curve shape regarding the change and modification useful in applications ranges (Fig. 16). A high hardness is associated with fewer pulses and a smaller range of defocus. A low hardness is obtained from closer pulses and a higher range of defocus.

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