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SURFACE HARDENING OVER 38MoCrAl09 STEEL BY YAG:Nd PULSE LASER

Sorin DOBROVICI[1], Nelu CAZACU[1], Liliana SAVA[2], Adolf BACLEA[3]
[1]Dept.of Metallurgy and Materials Science, Dunarea de Jos University of Galati, Romania,
[2]Unita VIG, Bucuresti, Romania,
[3]Socomar SRL, Sorento, Italy
e-mail: Nelu.Cazacu@ugal.ro, Sorin.Dobrovici@ugal.ro

ABSTRACT

Laser offers unique capabilities for high energy concentrations at small surfaces. Factors that have influences over interactions between laser beam and steel surfaces have very high control. Pulse laser YAG:Nd is usually used for cutting and welding. Paper is based on hardening experiments using KVANT 17 (YAG:Nd) pulse laser over 38MoCrAl09 steel. Results were investigated by hardness (HV5) macrographic and micrographic method.

KEYWORDS*:* laser, YAG:Nd, hardening, steel

1. Introduction

Lasers have progressed from a laboratory curiosity to an industrial tool. Most of today's industrial lasers output infrared light in the form of a beam that is converted to heat energy when it interacts with a material being processed. Cutting and welding laser systems use highly focused beams having power densities in excess of 106W/cm^2 to quickly melt and vaporize metals. Because these two industrial applications total nearly 95% of all laser systems sold, the use of lasers for surface modification is often overlooked, [6]. Superficial hardness is obtaining through beam energy distribution with low intensity for superficial heating of surface between melting points. The principal condition for process is energy uniform distribution over metallic material surface. That conduces to a uniform heating layer depth. Heating by power laser is characterized by high heating speed (pulse laser beam) from ambient temperature to austenitic domain.

After heating laser beam is stopped (pause), heat from superficial layer is transmitted by material diffusivity to adjacent volumes with very high speed and a local quenching is realized. Cooling speed is higher by critical quenching speed that means an auto quenching process and an exterior quenching mediun is unnecessary. The heat is lost by thermal conductivity from heating layer to material core and cooling speed is approaching to 1000°C/s.

Maximal temperature (°C) in superficial layer is given by relation:

$$T_{\max} = \frac{2F_0\sqrt{at}}{\lambda\sqrt{\pi}} \qquad (1)$$

where: F_0 – power density, W/cm^2, a – thermal diffusivity, cm^2/s, λ – thermal conductivity, W/°C·cm; t – time, s. After surface heating by pulse laser it is possible to obtain martensitic total transformations, but a quantity of residual austenite is normally present in microstructure. A cooling process is preferable to continue under 0°C.

Laser hardening is characterized by:

- Laser beam power increasing for a constant speed of part moving conduces to decreasing hardness
- Speed and beam power are control factor for depth hardening layer and for incident interaction surface
- Hardness obtained by laser quenching is higher by furnace heating and liquid quenching
- Laser hardening is easily optically controlled and depth of quenching layer is uniform
- Hardness is depending on thermal conductivity of material

Superficial hardening by YAG:Nd pulse laser is influenced by: steel hardenability (chemical composition), laser beam energy measured through accumulator supply of optical pumping system (at capacity battery connector), pulse frequency; focalization of laser beam at material surface (defocused).

2. Experimental conditions

Pulse laser KVANT 17 (made CIS) has solid active media by YAG:Nd ($Y_3Al_5O_{12}$).

Some important characteristics are: active media dimensions diameter 6.3 mm and length 100 mm; wave length 1.06 μm (IR); pulse time 2…5ms; pulse frequency 1…20 Hz; objective focal length 50 mm; surface diameter of interaction 0.3…1.3mm; pulse energy, min. 8J.

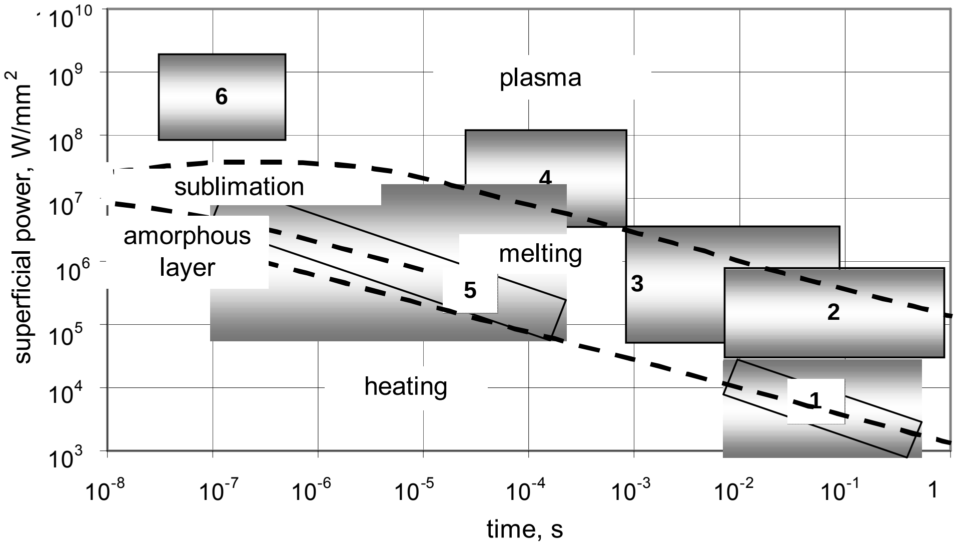

***Fig.1**. Basic processes and laser thermal applications in function of specific power and irradiation time: 1- superficial hardening, 2- alloying, 3- cutting and welding, 4-drilling, 5-glazing (amorphous layer) and superficial melting, 6- thermal pulse hardening, 0.*

***Table 1**. Relative comparison of different lasers used for heat treatments*

Laser type	Wave length	Absorption efficiency	Initial cost	Operating cost	Expectede life
	nm				
CO2	10,6	Low	Low	Moderate	High
YAG:Nd	1,06	Moderate/High	High	High	High
HPDD	800	High	Moderate	Low	Low

***Table 2**. Chemical composition for 38MoCrAlO9 (mass %)*

Steel	Chemical compositon								
	C	Mn	P	S	Si	Mo	Cr	Ni	Al
38MoCrAl09	0,410	0,530	0,022	0,011	0,330	0,180	1,350	0,110	0,860

For experiments was used 38MoCrAl09 steel with final heat treatments (quenching and tempering). Chemical composition is shown in Table 2. The experimental hardening regimes using YAG:Nd pulse laser are showing in Table 3. No used additional sample surface painting and no additional cooling system for quenching.

3. Results and discussion

Hardening surface was investigated macroscopically, micrographically and by surface hardness. In Fig. 2 and Fig. 3 are shown macrographs with typical surface after laser hardening. A local melting is present and surface craters were formed because a high local energy was concentrated at the material surfaces (Fig. 2). A normal surface hardening by laser beam is presented (Fig. 3) when oxidizing surfaces appear at interactions surfaces with oxygen because the temperature is in austenitic domain.

Macrographs for different samples are shown in Fig.4. Hardness increased for all experimental regimes (Fig.5). For 0 mm defocused hardness is higher over initial hardness 300 daN/mm^2 from 520 daN/mm^2 (550V) to 650 daN/mm^2 (900V). Hardness variation had a decreased zone and a increased zone. In the decreased zone hardness has a linear decrease with capacitor voltage from 520 daN/mm^2 to 380 daN/mm^2. The decreased is a result of high energy localized on a minimum surface at focal distance of objective (50mm) and practical defocused is zero. The minimum surface is 0.00785mm^2. Cooling capacity of material has a finite value and is determined by thermal conductivity of material.

In a second stage hardness is increasing because a cooling process from melt is present. A similar situation appears for 7.5mm defocused. For 5mm defocused and 550V…700V surface hardness have a linear increasing from 320daN/mm^2 to 650daN/mm^2.

***Table 3**. Pulse laser (YAG:Nd) hardening experimental regimes*

Experiment (sample)	Acumulator supply	Defocalization	Total pulse number	Pulse Frequency	Discharge current	Total time	Hardness HV_5 final
u.m.	V	mm	-	Hz	10^{-6}A	minute	daN/mm^2
1	550	0	410	0,3	34-58	22	520
2	600	0	430	0,3	34-60	23	425
3	650	0	460	0,3	34-60	25	388
4	700	0	406	0,3	34-60	20	466
5	750	0	411	0,3	40-70	23	477
6	550	2,5	415	0,3	30-48	22	466
7	600	2,5	420	0,3	32-52	23	603
8	650	2,5	430	0,3	36-58	17	435
9	700	2,5	440	0,3	38-64	32	441
10	750	2,5	420	0,3	42-70	20	376
11	550	5	410	0,3	28-48	22	332
12	600	5	365	0,3	30-52	20	473
13	650	5	410	0,3	34-60	25	549
14	700	5	410	0,3	38-64	20	644
15	750	5	410	0,3	40-68	23	460
16	550	7,5	410	0,3	24-46	22	487
17							-
18	600	7,5	466	0,3	30-52	20	412
19	650	7,5	410	0,3	42-64	22	325
20	700	7,5	430	0,3	14-38	21	412
21	750	7,5	436	0,3	38-66	23	376
22	800	7,5	440	0,3	38-66	20	441
23	850	7,5	450	0,3	38-66	22	566
24	900	7,5	460	0,3	38-66	21	540
25	950	7,5	465	0,3	38-70	23	549
26	650	10	406	0,3	38-70	23	283
27	700	10	411	0,3	38-70	23	310
28	750	10	415	0,3	38-70	23	306
29	800	10	420	0,3	38-70	23	391
30	850	10	430	0,3	38-70	23	418
31	850	10	440	0,3	38-76	23	325
32	850	10	420	0,3	38-76	23	401
33	900	10	430	0,3	38-76	23	367
34	950	10	445	0,3	38-76	23	453
c1	800	5	440	0,3	40-76	26	418
c2	850	5	436	0,3	50-82	22	575
c3	900	5	422	0,3	54-88	21	371
c4	950	5	430	0,3	58-96	23	401
35							
36	800	0	410	0,3	44-74	20	603
37	850	0	430	0,3	48-80	22	644
38	900	0	460	0,3	52-86	23	655
39	950	0	406	0,3	52-86	21	-
40	800	2,5	415	0,3	44-76	24	-
41	850	2,5	420	0,3	46-80	20	441
42	900	2,5	430	0,3	50-92	23	353
43	950	2,5	440	0,3	64-100	24	623

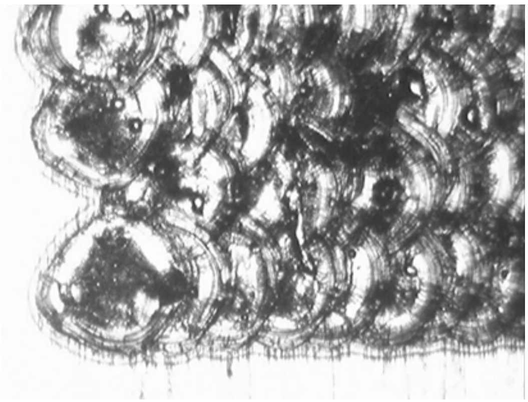

***Fig. 2**. Surface sample 3 (magnitude 350x).*

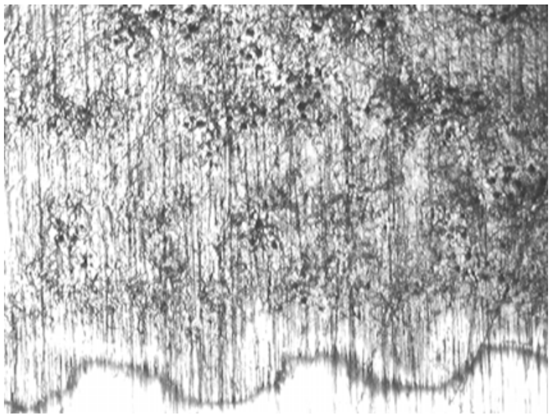

***Fig. 3.** Surface sample 11 (magnitude 350x).*

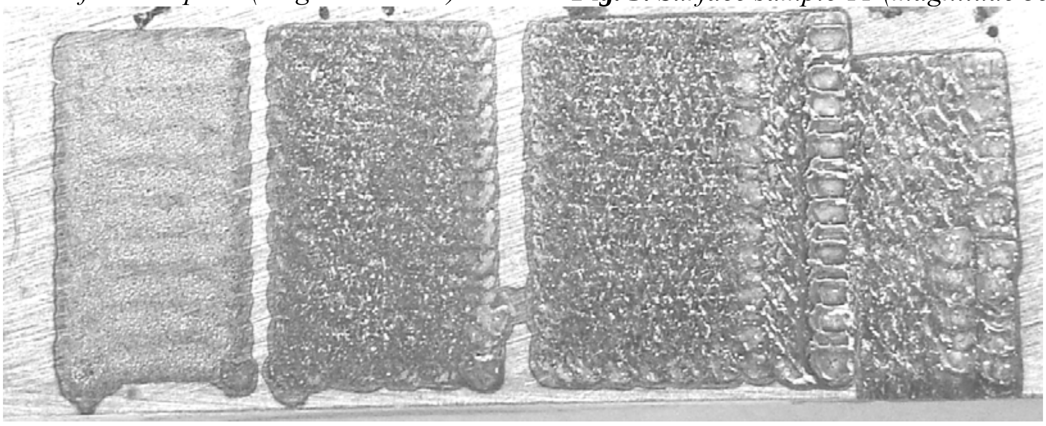

***Fig. 4.** Surface macrograph (samples 18, 19, 20, 21). Magnitude 10x*

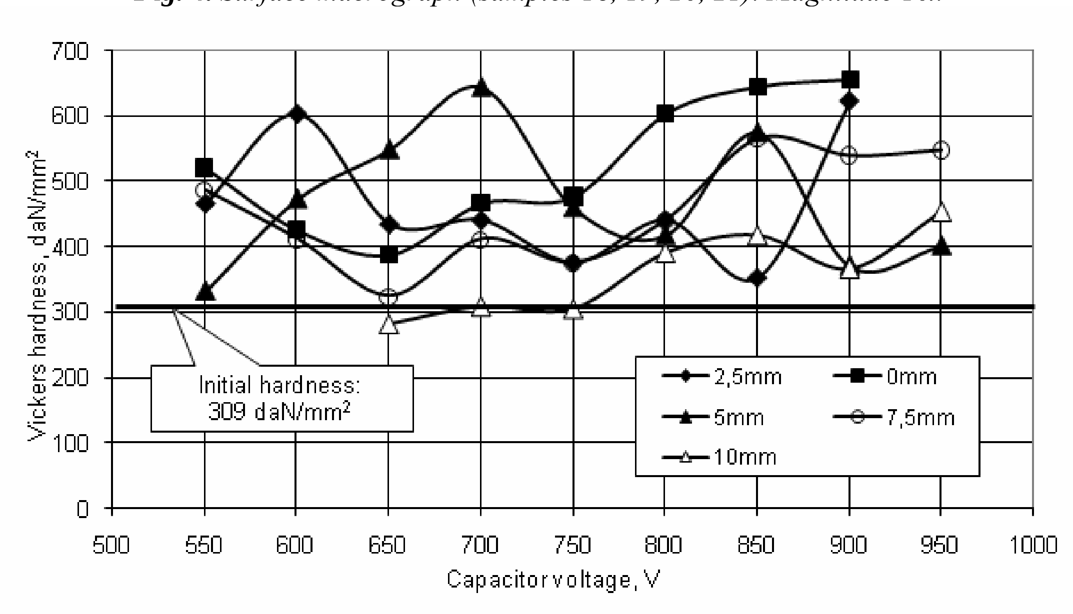

***Fig.5.** Hardness variations after pulse laser hardening for experimental regimes.*

For 700V capacitor voltage, a maximum of hardness was obtained, approx. 650daN/mm^2.

If accumulator supply is increasing over 700V, the energy of laser pulse beam is increasing and hardness is decreasing because local heating energy is higher and auto quenching time is too short.

Over 800V local melting is present and hardness is difficult to measure (Fig.2).

Surfaces are hardened by cooling from melt. A similar situation is for 2.5mm defocused. For 10mm defocused, hardness is increasing only for 750V… 850V capacitor voltage.

4. Conclusions

The KVANT 17 pulse laser with solid active media (YAG:Nd) is normally used for cutting and welding. By adapting a xy plotter controlled by computer, small pieces (samples) is moving relatively to laser beam. Interaction energy was controlled by defocused and indirect measurement of energy (capacitor voltage).

Hardening surfaces by pulse laser YAG:Nd is possible to realize for small surfaces. For 38MoCrAl09 steel an increasing of hardness from 309 daN/mm^2 to 650 daN/mm^2 was obtained under the presented experimental condition.

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