

LASER SURFACE HARDENING OF 51CrV4 STEEL

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ABSTRACT

The work presents the surface changes in microstructure and properties by quenching the 51CrV4 steel from liquid and solid phase, using a CO₂ continue laser wave with 900W power. In order to determine the hardening conditions, processing parameters on the geometry of the hardened layer and surface hardness were analyzed. Microhardness profile of heat affected zone was traced and correlated with structural changes. The effect of subsequent tempering was investigated.

KEYWORDS: laser hardening, steel, tempering, microstructure, microhardness.

1. Introduction

Laser beam superficial quenching is known as unconventional method of efficient local thermal treatment for cutting, cold deforming and trimming tools [1], [2], [3], [4], [5].

Laser beam gives an ultrarapidly heating speed of superficial layer (over 10^3 °C/s) that provides getting of fine inhomogeneous austenite or superficial melting. Relative small volume cooling lately, by thermal conductivity within mass of metal makes the cooling speed very rapidly to be, in order to allow an ultrarapidly solidification [6], followed by martensitic quenching with formation of ultrafine martensitic structure with high hardness, tenacity and wear resistance, [7], [8].

Hereby paper was originated by request of increasing the durability of knife blade from guillotine shares for paper cutting, made of 51CrV4 steel. It was intended to find the optimal laser quenching of this steel and thermal stability of the structure resulted in order to enlarge the use of steel to other tools for hot deforming or cutting.

2. Experimental conditions

Lab experiments were made on 12 mm thickness samples made of 51CrV4 grade steel as per SR EN 10083-1:1994 with 0,48%C; 0,33%Si;

0,97%Mn; 0,012%P; 0,020%S; 0,90%Cr; 0,10%Ni; 0,12%V; 0,04%Al; 0,13%Cu in its chemical

composition. Taking into consideration the use of material for cold cutting tools, samples were originally quenched in oil at 850°C and annealed at 150°C at 6550 MPa Vickers hardness (49N load).

Laser hardening was made in a CO₂ continuous wave laser installation as GT type of 1400W (Romania), endowed by x-y-z coordinate table. Single strips were drawn using a ZnSe laser beam focusing lens with 125 mm focal distance and a 900W power beam, defocused by 20 mm, that lead to a 1.8 mm laser beam equivalent diameter. In order to trace the radiating running influence upon hardening depth and level, surface scanning speed within 12,5...24,5 mm/s range were experimented. To increase laser radiation energy absorption it was used a zinc oxide absorbent cover on the surface to be worked. Ultrarapidly thermal cycle made by laser beam does not provide the chemical homogenization of austenite and when martensitic quenching a large quantity of residual austenite remains. In order to decrease the residual austenite quantity, after quenching by laser, samples were quenched in liquid nitrogen at negative temperatures [9].

To see the possibility of using the steel hardened by laser for hot cutting tools also, it was studied the structure thermal stability resulted on laser hardened samples, during this running, and tempered at 200, 300 and 400°C, for 45 minutes.

Structure and properties changes when laser quenching and tempering as well as their enlargement in depth were studied in laser strips cross section by micro structural and dimensional analysis and HV_{0,98} Vickers microhardness profile drawing (100g load) in thermal influenced layer depth. As global hardening index the

HV₄₉ Vickers (49N load) was determined on laser processed surface.

3. Results and Discussion

3.1 Microstructure analysis

Microstructure analysis in cross section of laser quenched strip pointed out that experimental running made the quenching since liquid phase. From surface into depth the following layers may be seen (figure 1 and figure 2-I):

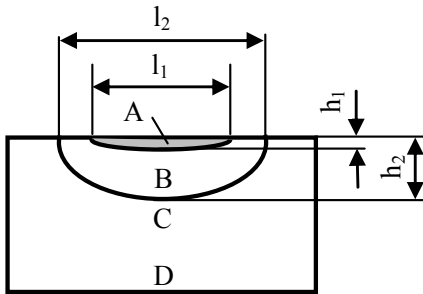


Figure 1. Scheme of layers in laser quenched strip cross section

A – quenched layer from liquid phase, got by heating over alloy liquidus point, rapidly solidifying and martensitic quenching; microstructure contains martensite columnar grains as finest as increasing the scanning speed;

B – quenched layer from solid phase by heating between Ac_3 and alloy solidus point. In layer bottom side it may be seen fine martensite needles and VN precipitates. At the top side, at higher temperatures, fine VN precipitates dissolving in austenite took place, austenite grains growing, martensite needles respectively. The layer is bottom limited by an intercritical quenching strip with troostite - martensite structure;

C – the tempered layer, by heating the Ac_1 subcritical basic material, where the tempering martensite is decomposed in a fine ferrite - carbide mixture;

D – thermal nonaffected basic material, by heating under its tempering temperature.

Microstructural analysis of tempered layers at different temperatures in the range of 200-400°C (figure 2 - IV) emphasizes the beginning of laser quenching martensite decomposing in ferrite -

carbide mixture, more enhanced by tempering temperature growth.

In table no.1 are given the results from layers dimensional analysis of experimental running laser quenched layers and in figure no.3 is shown the scanning speed influence upon them, where h_1 , l_1 mean the depth and width of quenched layer from liquid phase and h_2 , l_2 those of quenched layer from solid phase. Quenched layer dimensions decrease by scanning speed, more visible in quenched layer width from liquid phase.

Table 1 Dimensional analysis results

Sample code	Scanning speed [mm/s]	Laser quenched layers depth [mm]		Laser quenched layers width [mm]	
		h_1	h_2	l_1	l_2
1	26	0.037	0.46	0.81	2.41
2	24.5	0.062	0.46	0.95	2.42
3	23	0.074	0.56	1.12	2.63
4	21.5	0.086	0.59	1.23	2.65
5	20	0.104	0.59	1.36	2.68
6	18.5	0.128	0.63	1.57	2.63
7	17	0.148	0.67	1.67	2.65
8	15.5	0.170	0.69	1.75	2.70
9	14	0.185	0.70	1.86	2.73
10	12.5	0.202	0.77	1.79	2.99

3.2 Microhardness analysis

In figures no. 4 and 5 the HV_{0,98} microhardness variation in laser hardened layer from samples with code 4 and 8 is given.

Laser quenched layer from liquid and solid phase shows a higher microhardness of basic material processed in volume quenching and tempering at 150°C. Hardening is stronger when processing by high scanning speeds, in which quicker heating cycle provides more enhanced microstructure finishing as well as increased density of structural defects.

Liquid phase quenched layer microhardness is more reduced than that one of the layer quenched from solid phase, more enhanced at slower scanning speeds, in which the absorbed energy density gives larger size quenched layers in liquid phase with rougher dendrite structure. Later tempering reduces both layer hardness quenched by laser and that one of basic material, more enhanced when

tempering temperature increases. The tempered underlayer has a lower microhardness than basic material.

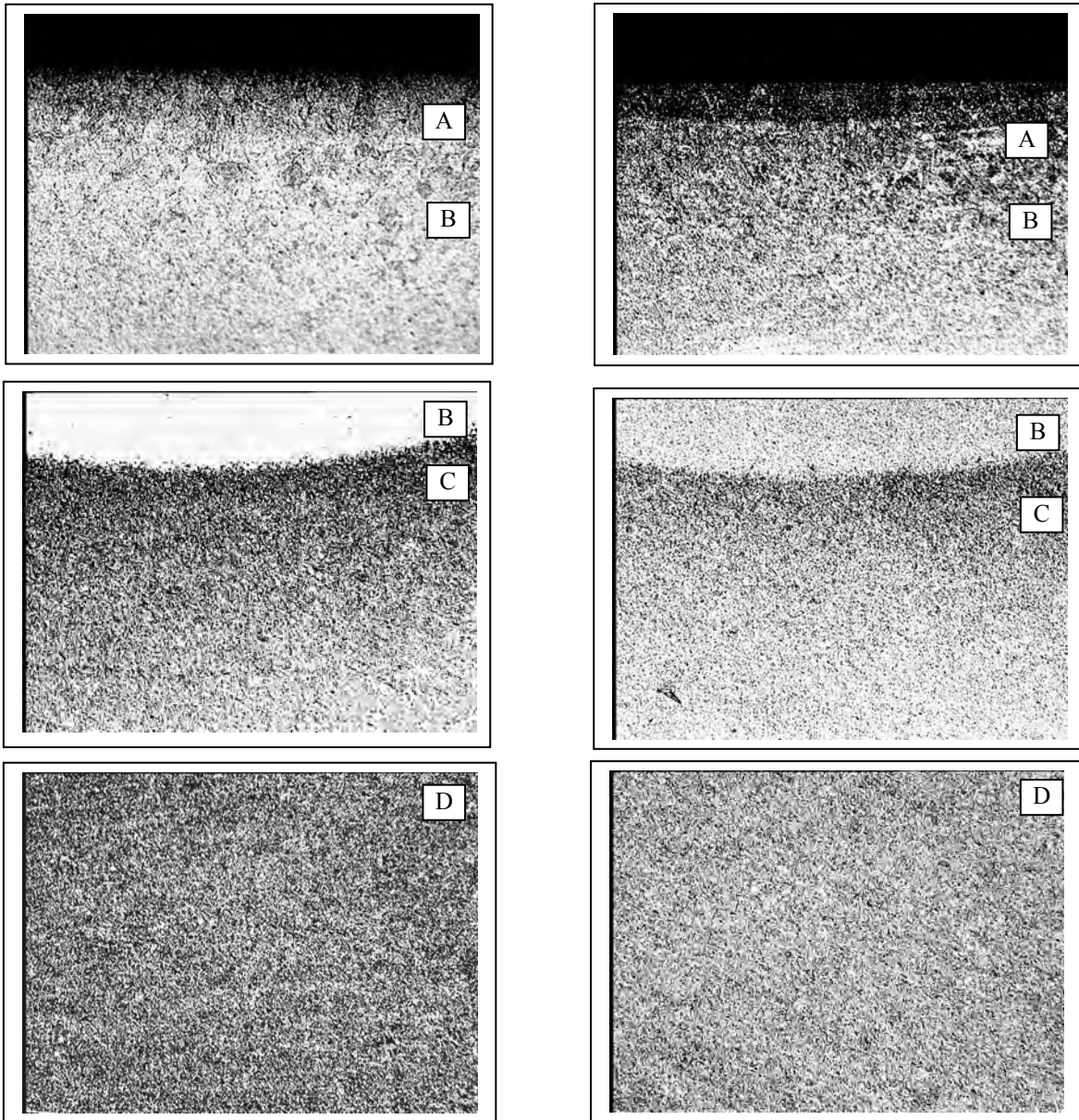


Figure 2. Microstructure of thermal influenced area (A,B,C) and of basic material (D):
I – after laser quenching in $P=900W$, $v=15,5mm/s$ running ; IV – after tempering at $400^{\circ}C$;
2% Nital Attack; x 200

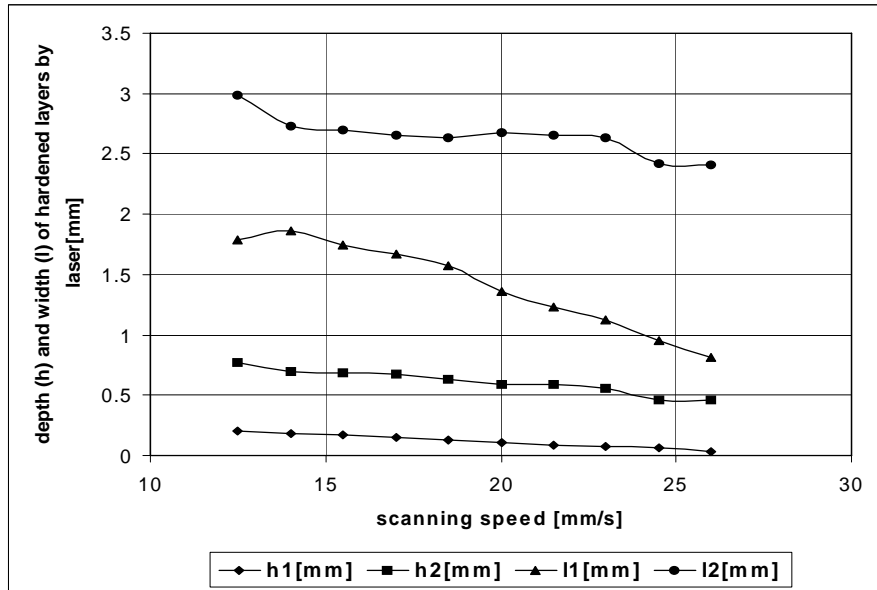


Figure 3. Variation of depth and width quenched by laser from liquid phase (h_1 , l_1) and solid phase (h_2 , l_2) with surface scanning speed.

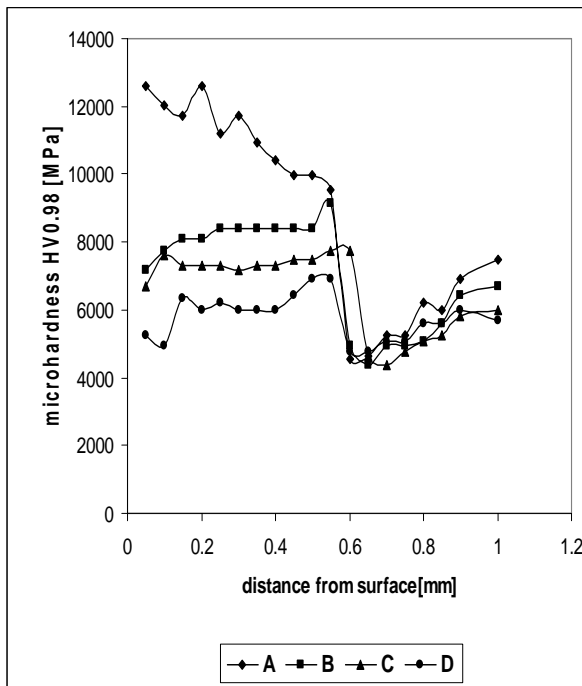


Figure 4. $HV_{0,98}$ microhardness variation in laser quenched layer at sample with code 4, quenched by laser in $P=900W$ and $v=21,5mm/s$ running

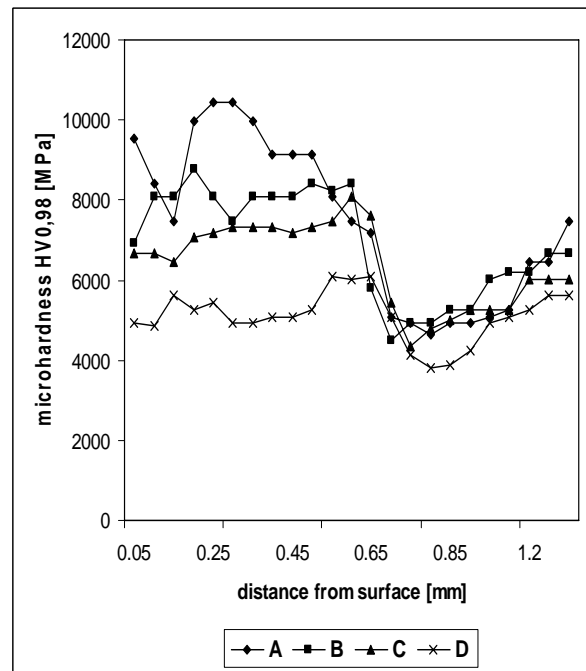


Figure 5. $HV_{0,98}$ microhardness variation in laser quenched layer depth at sample with code 8, quenched by laser in $P=900W$; $v=15,5mm/s$ running;

1.3 Surface hardness analysis

Hardening analysis on the processed surface integrates the microhardening effect and layers thickness. Hardness finding was performed on laser processed surface after superficial irregularities removed by grinding in 0.1 mm in depth since the surface. As a result, in running that made quenched layers from liquid state under 0.1 mm in thickness, they were removed.

In figure no.6 is given HV₄₉ hardness variation on the processed surface by scanning speed

compared to basic material hardness (0 scanning speed). Maximum hardening is equivalent to laser quenched layers from solid phase with scanning speeds ≥ 21.5 mm/s. At lower speeds the liquid phase quenched layer and rougher granulation decrease the superficial hardness. Laser quenched layer hardness decreases in the same time with tempering temperature increasing. Solid phase quenched layers hardness stays higher compared to those quenched from liquid phase. At 300°C solid phase quenched layers only keep higher the basic material hardness. At 400°C, their hardness is equal to basic material hardness.

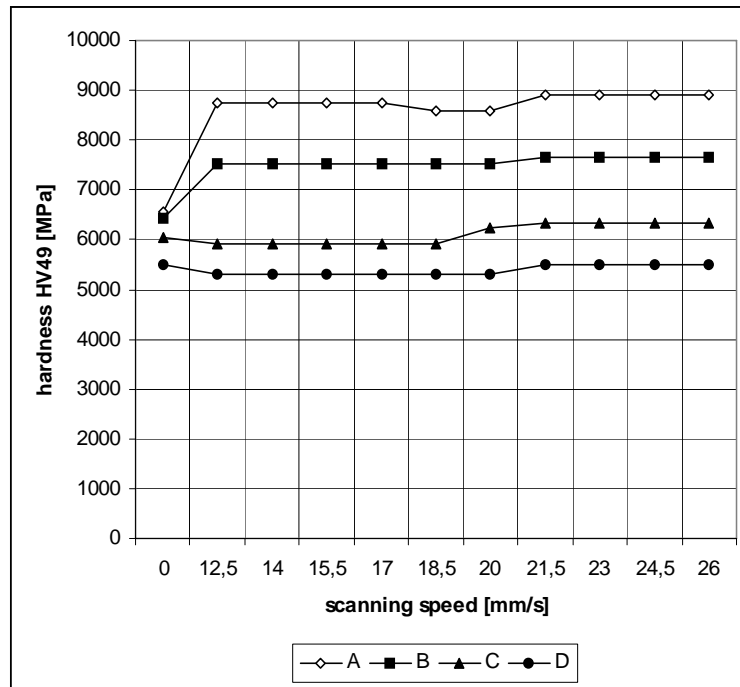


Figure 6. HV₄₉ superficial microhardness variation compared to scavenging speed after laser quenching (A), tempering at 200°C(B), 300°C(C) and 400°C (D)

2. Conclusions

Study made on 51CrV4 steel superficial laser quenching capacity pointed out that solid phase quenching is efficiently. In order to get the maximum quenching depth associated to 8910 MPa maximum superficial hardness, it is recommended laser quenching in P=900W; d=1,8mm; v=21.5mm running

that provides a solid phase quenched layer of 0.5 mm in depth after surface grinding.

Studying of laser quenching thermal stability showed that solid phase quenched layer hardness, in recommended running, decreases the tempering temperature so that at 400°C volume quenched material hardness is reached.

Laser quenching is recommended for cutting and cold or hot deforming tools that works up to maximum 300°C.

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