CAVITATION EROSION BEHAVIOR OF LASER NITRIDED 34CrNiMo6 ALLOYED STEEL

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Abstract

Some surface treatments that apply to the hydraulic equipment components, which operated at high hydrodynamic loads, in which appear the phenomenon of erosion by cavitation, shall be listed and laser nitriding. Before that operation, the steel was undergone thermal annealing treatments for improving machinability cutting, followed by martensitic quenching and a tempering to high temperature. By changing the laser beam power are changes the layer thickness enriched in nitrogen and thus the resistance to erosion by cavitation. The cavitation tests, carried out in accordance with the requirements of ASTM G32-2010 standards, followed by hardness measurements with micro-hardness HV0.3 and optical and electronic metallographic investigations, justifies the increasing resistances to erosion by cavitation of nitrided layer, compared with the volume heat treatment.

Keywords: Laser nitriding, erosion by cavitation, 34CrNiMo6 steel

1. INTRODUCERE

Two of the essential aims in the investigation of the phenomenon of cavitation, present in the hydrodynamic equipments, consists in the study of different types of materials, as well as the mechanical, thermal and thermochemical treatments, which can be applied to them in order to improve the resistance to cavitation erosion [1].

This paper aims to analysis the influence of microstructures generated by the thermochemical treatment by laser nitriding, in environment of pure nitrogen, on the behaviour to erosion by cavitation for 34CrNiMo6 alloyed steel, in hardening and tempering state, to the stresses generated by the impact with micro-jets and shock waves, produced during operation, by implosion of the cavitation bubbles from the hydrodynamic field [1]. Because the classic treatment by gas nitriding, requires time and cost quite high, we try to obtain the microstructures with similar characteristics, through laser nitriding.

Despite the high price of the equipment, cost of treatment and their realization time are much reduced, with the possibility by local treatment of interest areas, without affecting the base material.

Treatment process aims to keep the mechanical properties and microstructure obtained after the treatment of hardening and tempering, respectively increasing of hardness of surface layer, by applying the above mentioned treatment [2].

2. EXPERIMENTAL PROCEDURE

2.1. Material and testing apparatus

The researches were conducted on sets of samples processed from 34CrNiMo6 alloy steel (EN 10084-1998, No.:1.6582), hypo-eutectoid, with a broad in scope, used to manufacture the components for command, distribution and control devices from systems hydraulic drive. The chemical composition of the steel used in the experiments, is shown in **Table 1**, and the average values of the mechanical characteristics, for the delivery state, are shown in **Table 2**.

Table 1 The chemical composition of the steel examined

Steel	Component chemical elements, wt %							
	C	Si	Mn	Cr	Ni	P	S	Mo
34CrNiMo6	0.34	0.25	0.61	1.34	1.45	0.008	0.019	0.18

Table 2 Mechanical characteristics

Steel	TS N / mm^2	YS$_{0.2}$ N / mm^2	El.$_5$ %	RA %	HB -
34CrNiMo6	1300	1000	9	40	207

2.1. Applied treatments

The samples for testing were made from a cylindrical bar having a diameter of 25 mm, subjected to preliminary heat treatment of annealing for softening, followed by hardening and tempering, after which were machining by cutting, followed by polishing the surface of attack to a roughness Rz = 0.2 ÷ 0.5 µm. Subsequently mechanical processing, the samples were subjected to the thermochemical treatment by laser nitriding. Laser nitriding - is a modern alternative by thermochemical treatment, which consists of placing the specimens in a sealed chamber, from which previously the air was removed and replaced with pure nitrogen, at a pressure of 2-3 bar, and the sample surface was bombarded with laser pulses.

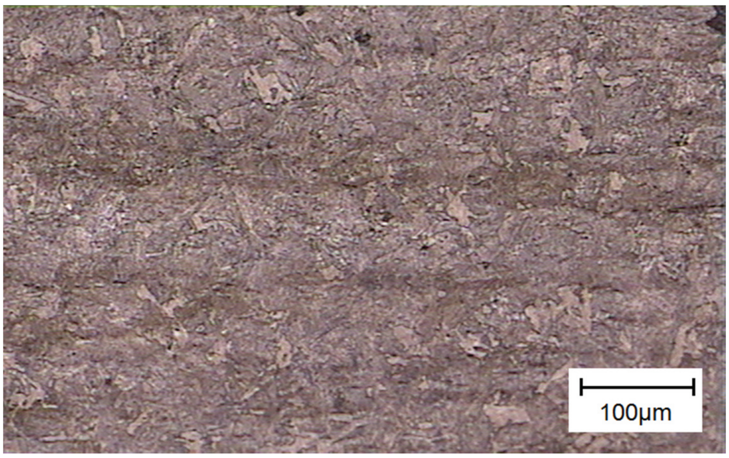
Under the action of the laser beam, the metal of surface layer is melted on a certain depth, which depends by parameters of the beam, on the sample surface is forming laser plasma, rich in nitrogen ions, which migrate by accelerated diffusion into the mass of molten.

Treatment was performed on a laser facility Nd-YAG, Trumpf HL 124 P LCU, at three regimes of power Pa = 240 W, Pb = 180 W, Pc = 120 W, following parameters being constants: pulse time t = 8 ms, repetition frequency of pulse 10 Hz, scan rate v = 4.07 mm·s^{-1}.

3. EVALUATION AND INTERPRETATION OF EXPERIMENTAL RESULTS

3.1. Microstructural investigations

Figure 1 shows the microstructure of the base material in hardened and tempered state, and in **Figure 2** a cross section through the nitrided specimen with laser is shown.



-a-

-b- -c-

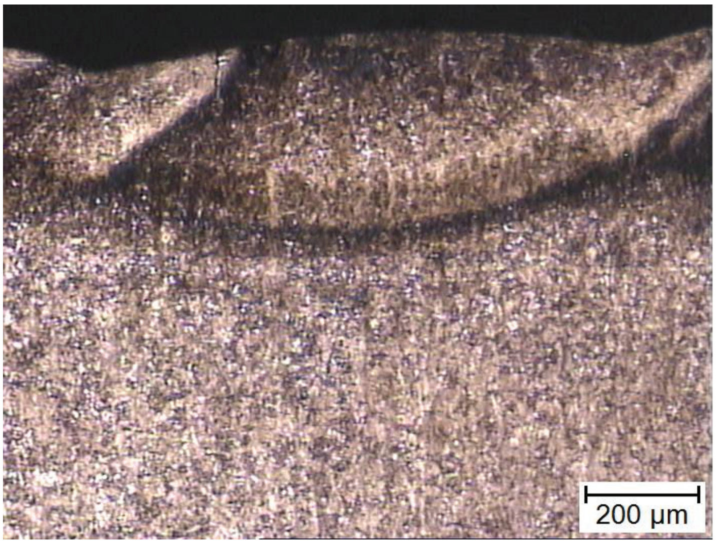
The material presents a structure of sorbite, formed of globular carbides in ferrite matrix, which ensures the best ratio between strength, ductility and toughness [1];

Figure 1 Specimen in hardened and tempered state: a - microstructure, b - the surface before of cavitation test, c - the cavitation surface after 165 minutes

The microscopic investigations highlighted the structural changes induced in the surface layer by thermochemical treatment. Their extension is dependent on power of laser beam.

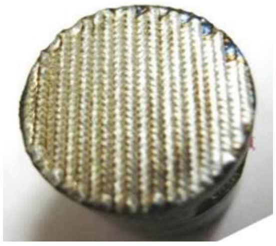
In this area, the material has a microstructure consisting of nitrides of type ε and γ' formed by accelerated diffusion of nitrogen in the melt, with a high degree of dispersion, which gives it a significant increase hardness.

The transition zone between the nitrided layer and the base material was quickly transformed in austenite, during the heating phase with the laser beam, and as a result of the critical speed of hardening relatively small of this steel, suffering to cooling in air, an intermediate transformation and mechanically un-stable.



- nitrided layer composed of nitrides of type ε and γ' incorporated in the matrix by solid solution α;

- transition layer with structure bainite - martensitic;
- basic material

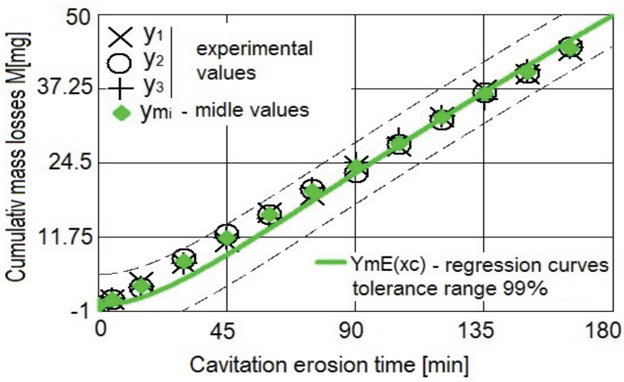


-a- -b- -c-

Figure 2 Laser nitrided specimen at power P = 180 W: a - nitrided layer microstructure, b - the surface before of cavitation test, c - the cavitation surface after 165 minutes

3.2. Research the behavior and resistance to cavitation

Cavitation curves have been prepared based on partial mass losses, in agreement with the international norms in field ASTM G32-2010 [2-4].



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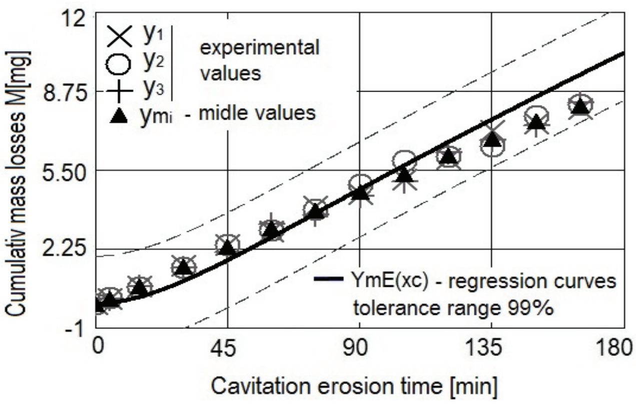

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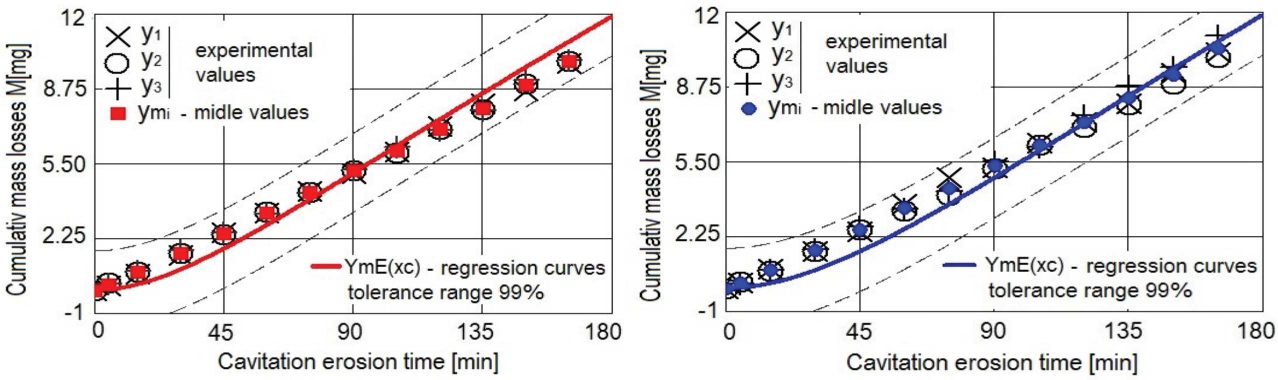

-c- -d-

Figure 3 Strips of dispersion for each set of samples treated: a) in hardened and tempered state, b) laser nitrided at P=240 W, c) laser nitrided at P=180 W, d) laser nitrided at P=120 W

To reduce errors of experiments, results were resorted to statistical processing of the, with check the errors level [3]. Such strips of dispersion were determined. **Figure 3** demonstrates the mass losses y1, y2, y3 determined in the laboratory, for the three samples from each set. Using standard estimation errors sxy and the polynomial regression curves YmE(xc), were determined interval limits, considering a tolerance of 99 %.

The dispersion of experimental points to mediation curve, much lower to nitrided surface, shows a uniformity of the microstructure of nitrided layer, respectively of mechanical characteristics that influence resistance to cavitation. The explanation is based on the structural changes generated from thermochemical nitriding treatment, as well as good adhesion of the surface layer at the substrate.

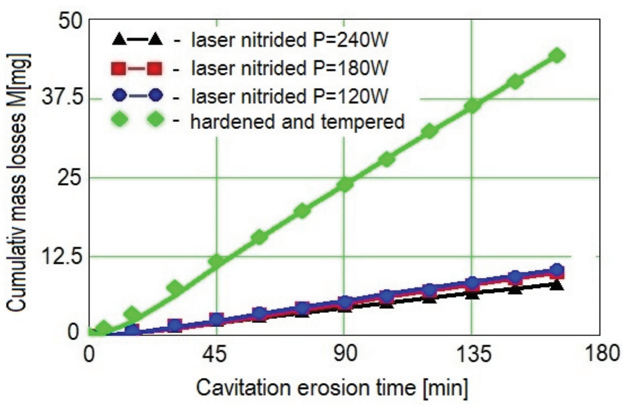

Figure 4 Variation of cumulative mass losses with cavitation time

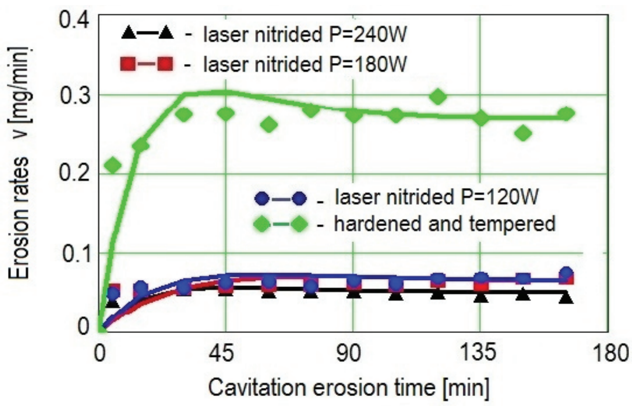

Figure 5 Variation of erosion rates with cavitation time

Comparing the values resulting from laser nitriding process, insignificant variations of cavitation parameter values, depending on the power of the pulse, is observed. For comparison hardened state with a tempered state, regime laser nitriding at 180 W will be deemed. It has the optimal combination between surface quality and mechanical characteristics resulting from treatment.

Analysis of variation curves of cumulative mass losses, M(t), **Figure 4** after 165 minute attack shows. It is observed a decrease of values by approx. 4.45 times, to the laser nitrided samples at P = 180 W, compared to the hardened and tempered state.

In **Figure 5** are shown the variations of erosion rates v(t) with duration of cavitation attack, from which results a decrease of their value by approx. 4.4 times, compared to the hardened and tempered state, with tendency to stabilize at maximum value, a specific behavior to materials with high hardness and very good resistance to cavitation. Nitrogen enrichment of the surface layer, favors a significant increase in hardness, determined by the nitrides formed with iron and alloying elements from the steel, which prevent the movement of atoms along the sliding plan. The high hardness values of the surface layer together with the higher compressive residual stress, is manifested by an increase in the fatigue limit and thus the resistance to erosion by cavitation.

The beginnings of cracks are determined by the cracking of the nitride particles and the limits of separation between them, as well as the separation limits between ferrite grains alloyed with nitrogen. The microstructure with high hardness to margin layer causes a small and uniform wear, with fine pinches without the appearance of deep craters. The process of hardening by laser nitriding has the advantage to shorten the time of treatment, respectively to focuses on certain areas, without affected in depth the base material. The disadvantage of this method is the high price of equipment, and the deformation of surface flatness to impact with the laser beam.

3.3. Micro-hardness tests

The variation of the hardness on the cross section to the laser nitrided samples is shown in **Figure 6**.

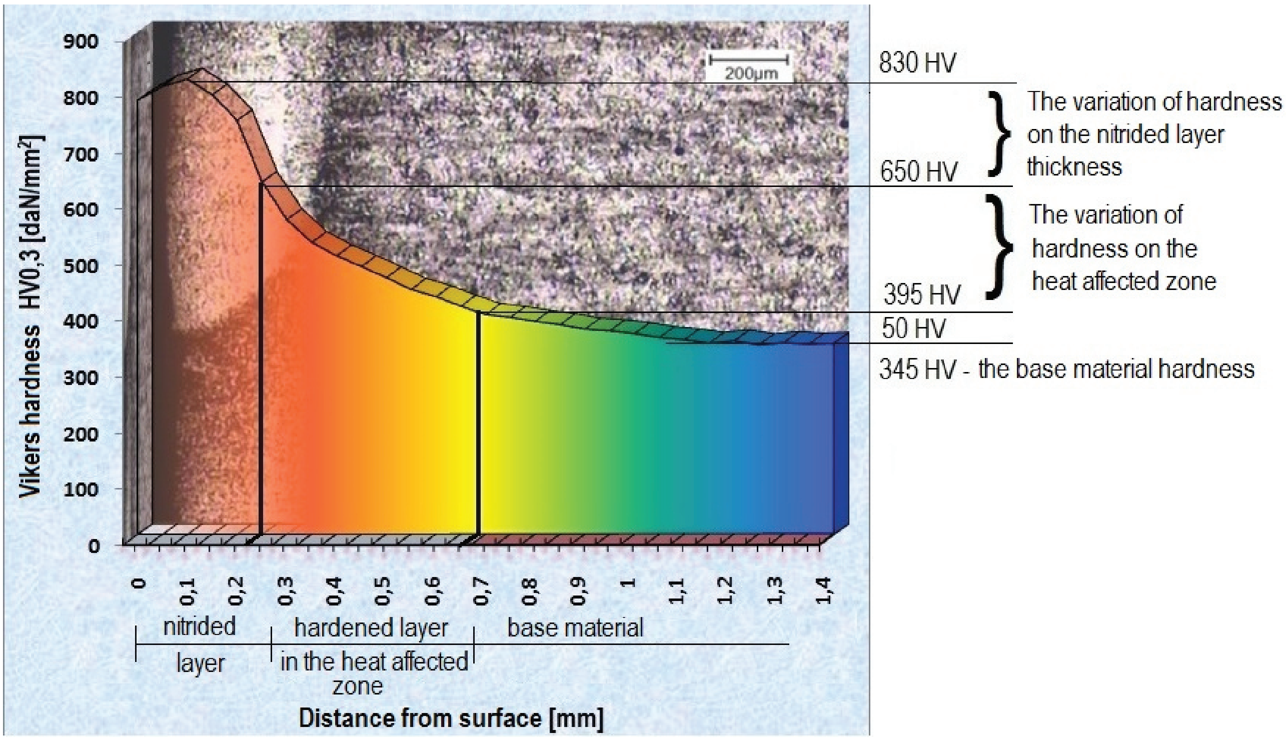

Figure 6 The variation of the hardness on the cross section to the laser nitrided samples at P = 180 W

In the marginal zone, appear values of hardness, HV0.3 corresponds to 770 ÷ 790, the maximum of which is located at a distance of 0.10 ÷ 0.15 mm from surface. In special literature, useful nitriding depth is considered as the distance from the surface to the point where hardness exceeds with 50 HV the core hardness. The analysis of micrographic image (**Figure 2**), combined with hardness gradient curve, demonstrates the fact that depth of nitrided layer formed in the melted area, under the action of laser beam is about 0.25 ÷ 0.30 mm. In the same picture **Figure 6** it can be seen that the total depth of the hardened layer by nitriding and hardening has values of 0.64 - 0.68 mm.

4. CONCLUSION

Application of the laser nitriding treatment, favors an increase of resistance to erosion by cavitation by approx 4.40 times as compared with the hardened and tempered state.

The reduced dispersion of the experimental points along the curve of mediation, in tolerance range of 99 %, is attesting a good behaviour of the microstructure generated by the applied treatment, the degradation of the surface tested to cavitation is slow, uniform and with extremely fine pitting.

The microstructure of material, after heat treatment of hardening and tempering is consisting of allied ferrite and globular carbides, and ensures the best balance between the mechanical strength characteristics, ductility and toughness.

The simple and complex nitrides, embedded in allied ferrite matrix with nitrogen from the surface layer, determine a significant increase of hardness on a layer depth by approx 0.3 mm, the maximum of this values is HV0.3 corresponds to 770 ÷ 790 in a depth of 0.1 mm.

Although the nitriding treatment involves additional costs, it is fully justified by the extended life of the equipment hydraulic elements, working in conditions of cavitation, reducing maintenance time and costs during exploitation.

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