Cavitation Erosion Resistance of Laser Beam Nitride Layers of X5CrNi18-10 Stainless Steel

ILARE BORDEASU[1]*, CORNELIA LAURA SALCIANU[1]*, MIRCEA OCTAVIAN POPOVICIU[2], ION MITELEA[1]
[1] Politechnica University of Timisoara, 1 Mihai Viteazul Blvd., 300222, Timisoara, Romania
[2]Academy of Romanian Scientists, Timisoara Branch, 1 Mihai Viteazul Blvd., 300222, Timisoara, Romania

The use of nitration in technical applications, as thermochemical treatment, regardless of the used method (ionic, gas or laser beam nitration) is realized to obtain a nitrogen rich layer, which increase the resistance to shock or abrasion, as a result of the high hardness obtained. All the previous cavitation researches showed that hardness is an important mechanical properties, for cavitation erosion resistance increase. The present paper show some results regarding the cavitation erosion behavior of laser beam nitrated layers. As basic material was used the austenitic stainless steel X5CrNi18-10. This material is frequently used for manufacturing details subjected to cavitation, such as valves, drawers of hydraulic distribution and regulation devices, or the retaining ring for butterfly valves. There were used three power regimes of the laser beams: 120 W, 180 W and 240 W. To obtain cavitation erosion was used the standard device with piezo-ceramic crystals of Timisoara Polytechnic University Cavitation Laboratory. The cavitation erosion comparisons, both with the basic material subjected only to the common thermochemical treatments and with the laboratory cavitation standard steel (OH12NDL), show that the nitrated surfaces presents increased cavitation erosion behavior, the principal factor being the important hardness increase of the nitrated layer. We mention also, that for higher laser beam powers the thickness of the nitrated layer increases. All the images obtained at the end of tests show that the cavitation exposure was stopped before overtaking the nitrated layer. So, all our results concern only the hardened layers.

Keywords: cavitation erosion resistance, laser beam nitride layers, stainless steel, cavitation erosion characteristic curves, hardness

The use of performant measuring and shooting equipment for tracking the evolution of cavitation bubbles show that the damages suffered by the exposed solid surfaces is caused by shocks with very high pressure (with the magnitude order of thousand Pascal) [1-10], inducing in the superficial layers tensions greater than those of the inter and trans crystalline bounds. The majority of the undertaken studies and researches works regarding the material destruction show that the hardness value is the principal factor responsible for the erosion degree. The researches and studies undertaken by Hammitt and other [1,9,10], with regard of the hardness effect upon the surface resistance, show that the mean depth erosion (MDE) decreases with the value of hardness. Based on these results, the researchers begun to use the increase of the hardness of the exposed area, but without bringing them into the breakable domain. An excellent technique for this purpose is nitration.

The laser beam nitration was increasingly used in the last time, [11-14] due to the fact that the striated and hard layers having a great content of nitrogen does not change the chemical composition of the basic structure. The nitrated layer has an excellent adherence with the sublayer and his depth depend significantly to the laser beam power. The striations resulting from the displacement of the laser beam can be reduced through grinding or polishing, with the condition that the depth of the nitrated layer to remain thick enough. The most numerous application of nitration are for the pieces with a simple geometry and reduced dimensions which must not have great fatigue resistance but must show an improved behavior for shock absorption, as in the case of those produced by a fluid working in cavitation.

Experimental part

Researched material

Nitrating procedure

The researched material is the stainless austenitic steel X5CrNi18-10, with good welding ability and used for details requiring good corrosion resistance in fresh water, see water, nitric acid, sulfuric acid and other such aggressive media [15-17]. In conformity with the Schäffler diagram [15] it is composed by 88 % austenite and 12 % d ferrite.

The chemical composition and mechanical properties, specified by the producer [15, 18] and verified in the laboratories of Timisoara Polytechnic University are: 0.046 %C, 17.95 % Cr, 8.11 % Ni, 1.46 % Mn, 0.89 % Si, 0.27 % Cu, 0.16 % W, 0.024 % P, 0.019 % S, 0.09 % N, the remainder being Fe; R_m = 550 MPa, $R_{p0.2}$=195 MPa, Brinell hardness HB = 183 daN/mm^2 (approximate HV = 192 daN/mm^2), elongation at break A_5 = 45 %.

For common parts, this material is used after quenching at 1050°C, with a maintenance duration of 25 min and with sudden cooling in water. The mean hardness of the superficial layer, measured after quenching is198 HV1. This parameter was carefully measured because in conformity with the studies of Garcia and other [9] but also taking into account the older studies of our laboratory [19-22], hardness is the principal factor influencing the cavitation erosion resistance. The chosen material for researches was adopted, taking into account his large use in various applications such as the construction of the valves working in cavitation flows with fresh or salt water. In these application in addition to the corrosive effect, cavitation is also present [15, 17, 19, 22, 23].

The laser beam nitration, as an industrial process for treating the surfaces exposed for different stresses is more

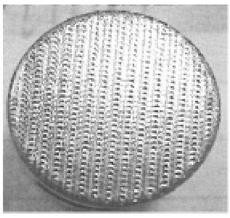
*email: ilare.bordeasu@upt.ro, ilarica59@gmail.com, Phone: 0723650248; salcianu.laura@yahoo.com, Phone: 0740159673

and more common because is very easy to be applied and in the same time it realize good functioning layers without substantially influencing the basic material [12, 14, 15]. This advantage is given by the nitration with a transversal speed of about 100 mm/s [12], achieving a strong dissolution of nitrogen and so forming a hard layer. For the nitration of cavitation erosion samples was used the Trumpf HL 124 P LCU device equipped with programmable pulsed laser Nd-YAG, (fig.1), found in the endowment of

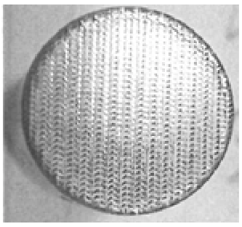
Fig. 1. HL 124P LCU device

the Timisoara National Institute for Researches in the Field of Welding and Material Testing.

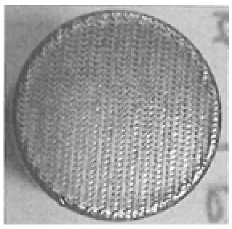
The nitration procedure consisted in scanning the specimen surfaces with a laser beam, in a pure nitrogen atmosphere. The nitrogen flow was 33 l/min. The laser beam parameters were: the impulse frequency 10 Hz and three different impulse powers: 120 W, 180 W, 240 W with an exposure time of 8 ms.



P_{impuls}= 120 W



P_{impuls}= 180 W



P_{impuls}= 240 W

Fig.2. Photos of the nitrate surfaces

In figure 2 are presented the images of the laser nitrated surfaces for each power impulse, the images being realized with a Canon Power Shot photographic device.

The images in figure 2 show the peculiar form of the nitrated layer, with waves formed by the movement of the laser beam displacement. The wave fines increase with the impulse power but the important fact was the influence upon the cavitation erosion resistance. Realized in a transversal section, in conformity with the figure 3 scheme, the measurements show a gradual reduction of the hardness in the 55mm thick nitrated layer from approximate (550 ... 600) HV0.3 measured at the layer

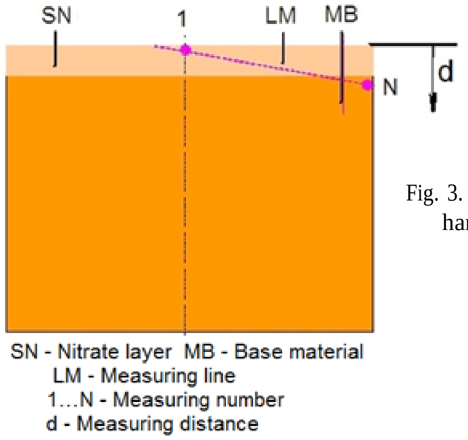


Fig. 3. Nitrated layers hardness [15]

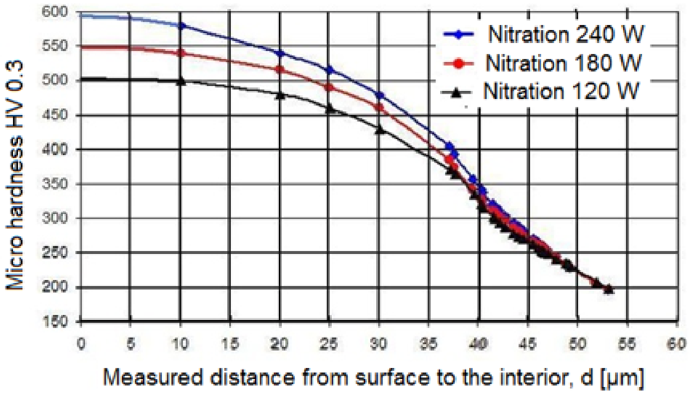


Fig. 4. Hardness variation in the section of laser nitrated surface [15]

surface to approximate 200 HV0.3 in the area near the basic material figure 4.

Results and discussions

The cavitation erosion resistance of different samples was obtained by using a Standard Vibratory Device ASTM G32-2010, with piezo ceramic crystals, in the Cavitation Laboratory of Timisoara Polytechnic University [24]. In conformity with the standard requirements [25] and the laboratory habits, for each power regime were tested three specimens. Before the tests the exposed surface was polished at a roughness of Ra = 0.08 mm, the thickness of the deposited layer remaining between 142 and 210 µm (fig. 12). Also the cylindrical surface of the nitrated layer was turned with a lathe at the sample diameter (15.8 mm), in order to eliminate the irregularities resulting from the melting with the laser beam. The procedures for preparing,

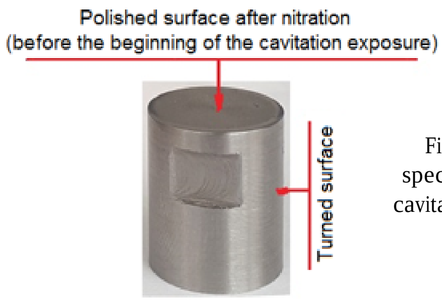


Fig.5. Photo of the specimen prepared for cavitation erosion testing

testing and data recording were the standard ones, used in our laboratory [6, 8, 12, 14, 15, 17, 19, 20, 24]. In figure 5 it can be seen a photograph of the specimen.

The behavior of the laser treated layers at cavitation erosion are presented in the figure 6-8. There are given both the evolution of the mean depth erosion MDE(t) and the mean depth erosion rate MDER(t). Examining the evolution of the curves MDE(t) and MDER(t) as well as the

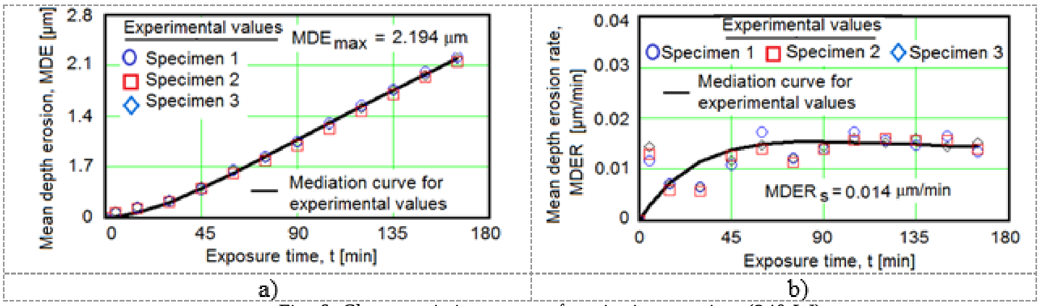


Fig. 6. Characteristic curves of cavitation erosion (240 W)

a) Mean depth erosion against cavitation exposure time; b) Mean depth erosion rate against cavitation exposure time

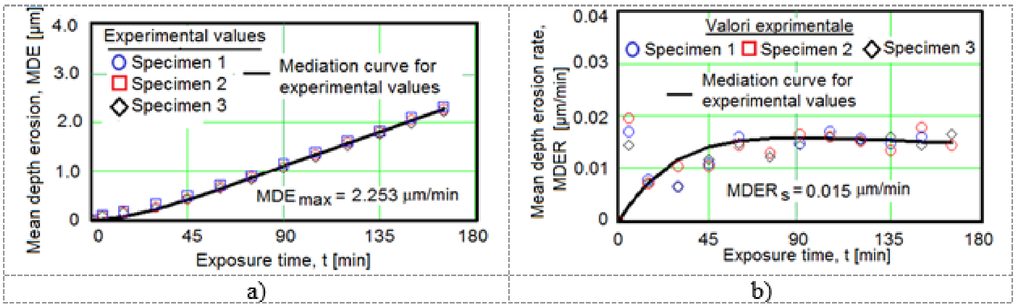


Fig. 7. Cavitation erosion characteristic curves (180 W)

a) Mean depth erosion against cavitation exposure time; b) Mean depth erosion rate against cavitation exposure time

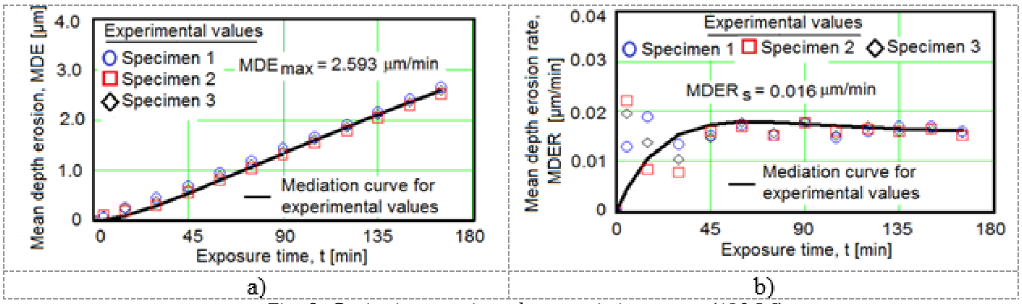


Fig. 8. Cavitation erosion characteristic curves (120 W)

a)Mean depth erosion against cavitation exposure time ; b) Mean depth erosion rate against cavitation exposure time

scatter of the experimental points, the following conclusions can be drawn:

-in the first 15-30 min of testing, the nitrated surfaces for all three specimens and for all the treatment regimes, have a different behavior and after the values of MDER parameter (fig. 6b, 7b, 8b), it can be created a false impression that the nitrated layer has at the begining a week behavior at cavitation erosion. Taking into account the experience of over 70 years of testing [22] this interval must not be considered as characteristic one for the resistance of the material. Upon us, this behavior is the result of the existence of some week components such as oxides and poorly adherent crusts, which were not eliminated in the process of cleaning/washing procedures and are rapid eliminated at the beginning of the tests;

-all three specimens of the same material show similar behavior, expressed by the superposition of the measured points on the interval 45…165 min of cavitation exposure;

-the measured values are characteristic for materials with excellent cavitation erosion resistance [22]; the conclusion is confirmed also by the linear evolution of the curves MDE(t), on the interval 45-165 min and by the tendency of the curve MDER(t) to be stable at the maximum value of the erosion velocity;

-the reduced scatter of the experimental values (after minute 45), around the mediation curves are the result of the uniform distribution of the hardness in the entire area of the nitrated surface, as a result of the accuracy of the nitration procedure respecting the working parameters (impulse power, speed of beam movement, impulse duration); this conclusion is confirmed also by the photo images of the surfaces at the test end, (fig. 9);

-comparing the three different procedures, the surfaces nitrated with an impulse power of 240 W give the best behavior to cavitation erosion, presenting the most reduced scatter and even the superposition of all measured values in the 45-165 minute interval of cavitation exposure, (fig. 8b).

The images of figure 9, correlated with the maximum

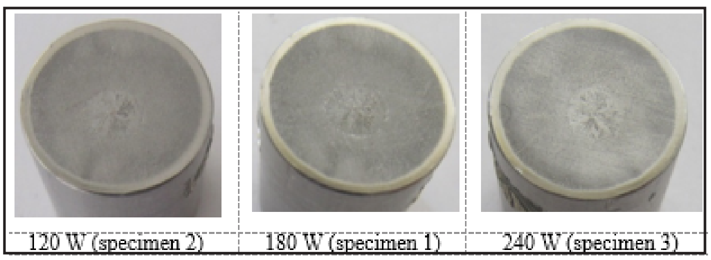


Fig. 9. Images of the eroded nitrated layer after 165 min of exposure to cavitation

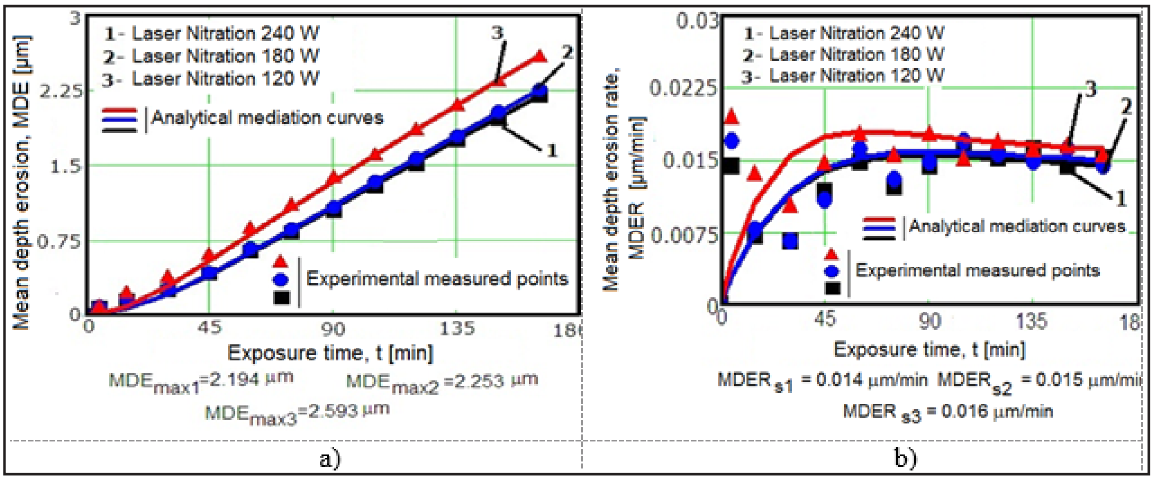


Fig.10. Comparisons of the characteristic cavitation erosion curves: a)Mean depth erosion against cavitation exposure time ; b)Mean depth erosion rate against cavitation exposure time

depth values of the erosion from figure 6-8, show that the penetration of cavitation erosion affect in a small measure the nitrated layer remained after polishing. We appreciate that this reduced depth of the erosion is the result of the great hardness of the treated layer (550…600) $HV_{0.3}$, (fig. 4).

To identify which one of the three nitration regimes give the greatest resistance to cavitation erosion, in figure 10 there are made comparisons between the curves MDE(t) and MDER(t). The experimental values presented in figure 10 for MDE and MDER are means for the three tested specimens.

The mediation curves shape in figure 10 show that the differences between the evolutions of the erosion depth MDE(t) but also those of mean depth erosion rates MDER(t), for the specimens nitrated with laser beams at powers of 120 W and 180 W are extremely small. The use of laser beams with a power of 240 W increase substantially the cavitation erosion resistance. Taking as comparison element only the final measured values of the cavitation erosion resistance, we obtain the following conclusions:

- the value MDE_{max} is approximately with 18% greater and the value $MDER_s$ with approximately 14% greater for the power 240 W in comparison with the use of power 120 W,

and

- the value MDE_{max} is approximately with 15% greater and the value $MDER_s$ with approximately 7% greater; for the power 240 W in comparison with the use of power 180 W.

Evidently, those modifications appear as a result of the hardness increases (fig. 4) of the nitrated surfaces (approx. 600 $HV_{0.3}$ for the laser beam power of 240 W, approx. 550 $HV_{0.3}$ for the laser power of 180 W and approx. 500 $HV_{0.3}$, for the laser power of 120 W).

It can be seen that the increase of the cavitation erosion resistance (regardless of the chosen parameter MDE_{max} or MDR_s) is not directly proportional with the increase of the laser beam power (of about 100 % respectively 33 %, taking as reference the laser beam power of 120 W).

For the evaluation of the cavitation erosion increase realized with the steel X5CrNi18-10 nitrated with laser beams, in figure 11 are made comparisons with both: the same steel in quenched state and the stainless steel OH12 NDL considered with good cavitation erosion resistance and taken as standard steel in our Cavitation Erosion Laboratory [, 14, 15, 17, 22, 24]. As comparison parameters were taken MDE_{max} and $R_{cav} = 1/MDER_S$.

Regardless of the used parameter, the data in figure 11 histogram confirm that the laser beam nitrated surfaces, regardless of the power used (120 W, 180 W or 240 W) receive a very high cavitation erosion resistance as the result of the great hardness of the nitrated surface. The increases in comparison with the standard cavitation erosion steel OH12NDL is:

- *after the values of the cavitation erosion resistance* R_{cav}**:** through nitration with the power 240 W is approximately 12 times greater; through nitration with the power 180 W is approximately 11 times greater; through nitration with the power 120 W is approximately 10 times greater;

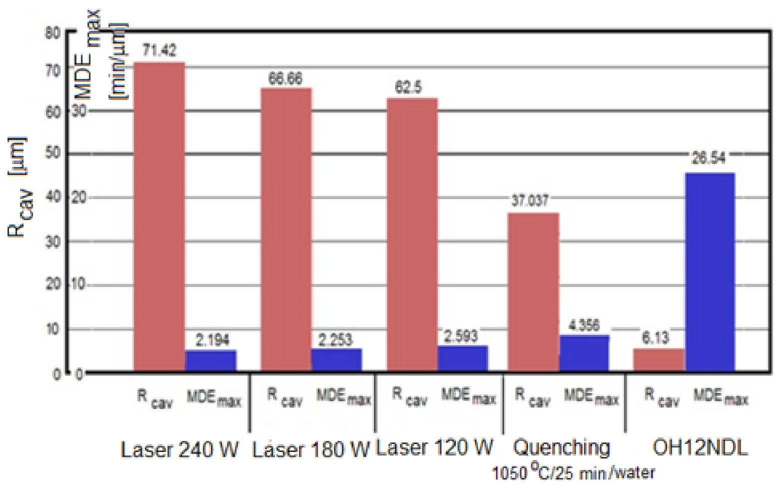
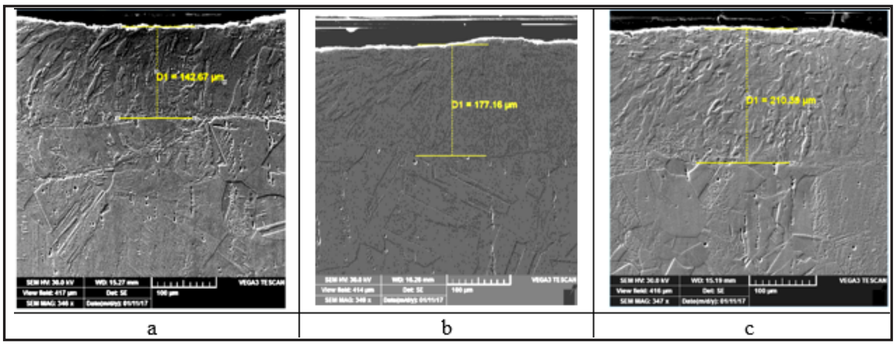
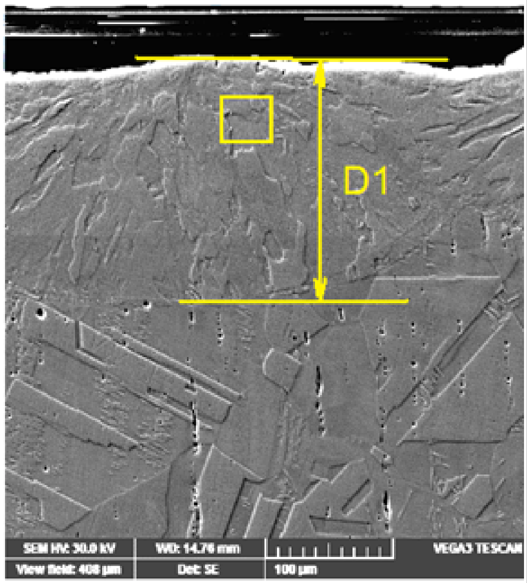


Fig. 11. Appreciation of cavitation erosion increase by comparisons between the laser treated samples with the same steel only quenched and the standard steel OH12NDL

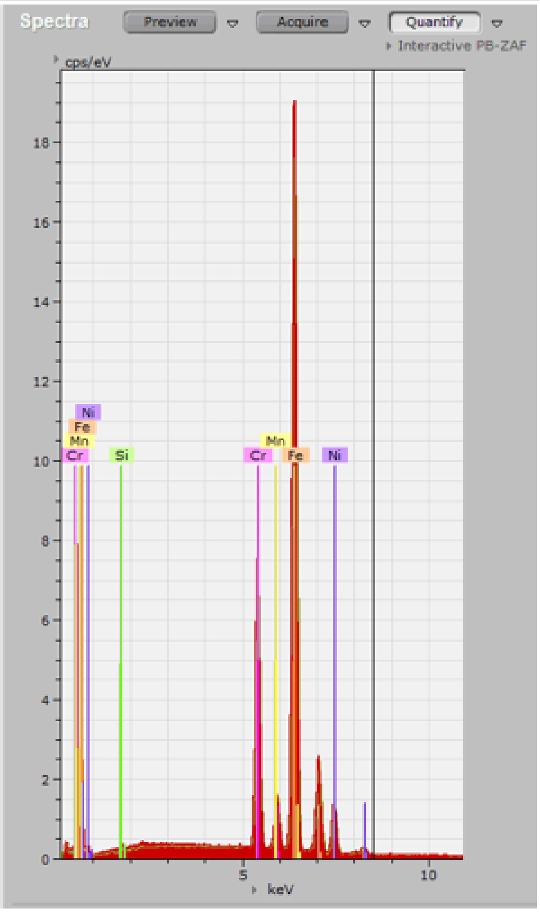


a b c

Fig. 12. Images showing the nitrated layer and the base material
a) P = 120 W; b) P = 180 W; c) P = 240 W



a



b

	Series	unn. C [wt.%]	nor. C [wt.%]	Atom C [at.%]	Error (1 Sigma) [wt.%]
Silicon	K series	0.37	0.38	0.68	0.06
Chromium	K series	17.98	18.02	17.73	0.51
Manganese	K series	0.55	0.55	0.51	0.05
Iron	K series	70.54	70.67	64.75	1.83
Nickel	K series	7.14	7.16	6.24	0.24
Molybdenum	K series	0.55	0.55	0.29	0.17
Nitrogen	K series	2.68	2.68	9.79	0.99
	Total	99.82	100.00	100.00	

c

Fig. 13. Spectrographic analyze of the nitrated layer subjected to a laser beam having 240 W impulse power
a) analyzed zone; b) spectrograms c) chemical composition

- *after the values of mean depth erosion MDE_{max}, obtained in 165 min of explosion:* through laser nitration with 240 W is approximately 12 greater; through laser nitration with 180 W is approximately 11.8; through laser nitration with 120 W is approximately 10 greater;

The increases in comparison with the quenched state of the steel X5CrNi18-10 is:

- *after the value of the cavitation erosion resistance R_{cav}*: by nitration with laser power 240W is 1.9 times greater; by nitration with laser power 180W is 1.8 times greater; by nitration with laser power 120W is 1.7 times greater;

- *after the values of mean depth erosion MDE_{max}, obtained after an exposure of 165 min are:* after nitration with 180 W is approximately 1.92 times greater; after nitration with 120 W is approximately 1.58 times greater.

The results of scanning electron microscopy, on the sectioned specimens, after 165 min of cavitation exposure, (fig.12a-12.c), are in excellent concordance with the previous presented observations. On one hand, they demonstrate the efficiency of the nitration treatment upon the improvement of the behavior to cavitation erosion and on the other hand, the influence of the laser beam power upon the thickness of the layer enriched in nitrogen (D1). From the figures it results that for great powers of the laser beams the thickness of the layer after cavitation exposure is greater (compare fig. 6a, 7a, 8a and 10a with 12a, 12b and 12c).

The EDX analyzes of some micro volumes of the nitrated layer before and after the cavitation exposure (fig. 13) show that the cavitation erosion does not determine modification of the steel chemical composition.

Conclusions

The three tested nitration regimes applied to the steel X5CrNi18-10, as a result of the hardness realized, compared with those of the standard steel OH12NDL and those obtained through simply quenching the tested steel (maintained 25 min at 1050°C and sudden cooling in water), has at result a great improvement at cavitation erosion resistance**.** The thermochemical nitration does not have significant modifications of the chemical composition of the metal; it was done only a nitrogen enrichment of the superficial layer, with great effects upon the hardness.

As can be seen in the figures of specimen section, during the experimental exposure to cavitation the erosion, the nitrated layers were not exceed.

The big increases of the resistance to cavitation erosion recommend this treatment for details subjected to intense cavitation erosion such as occur in hydro-mechanical equipment. The great problem remain the dimension of the detail and the complexity of the geometrical configuration. After our opinion the procedure can be easily applied to rings used for fixing the butterfly vanes, valves, seats of valves in pumping systems or irrigation.

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