INFLUENCE OF NITRIDING THERMOCHEMICAL TREATMENTS UPON CAVITATION EROSION RESISTANCE OF DUPLEX X2CrNiMoN22-5-3 STAINLESS STEELS

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Abstract: *The duplex stainless steels X2CrNiMoN22-5-3 is widely used today, in chemical industry, in shipbuilding industry, in construction industry, in food industry etc., because it has good resistance to intercrystalline corrosion and, better physical and mechanical properties then austenitic steels. The mechanical properties of those steels, depends very much on their chemical composition and on the applied treatment. This paper presents the effect and the advantage of applying nitrogen during the nitriding thermochemical process upon the cavitation erosion resistance of the stainless steels X2CrNiMoN22-5-3, in comparison with the quenching heat treatment and low tempering. The researches were undertaken at Timisoara "Politehnica" University in the Cavitation Laboratory, using a piezoelectric crystal vibratory device T2. By comparing the interpretation of the specific curves M(t) and v(t) (cumulative mass losses and erosion rate) of the two analyzed treatment procedures (one of gas nitriding (ammonia), and the second of quenching and oven cooling) with the ones of standard steel OH12NDL, utilized in Kaplan turbine blades used in Romania, in the hydropower called "Portile de fier", results in a significant increase of the resistance against the vibratory cavitation erosion. Also, it is observed and certified that gas nitriding treatment, gives to stainless steel X2CrNiMoN22-5-3 a higher cavitation resistance then the one resulting from quenching heat treatment. Therefore, the test results shows that, the type of treatment applied to stainless steel X2CrNiMoN22-5-3, influence the increase of the exposed surface to cavitation erosion resistance.*

Keywords*: duplex stainless steel, gas nitriding, quenching and oven cooling, cavitation resistance, the mean depth erosion, erosion rate, cumulative mass losses*

1. Introduction

Destroying the solid materials through cavitation, represents a complex phenomenon, involving a hydrodynamic and mechanical aspect according to their material fatigue life. [1], [2]. The research done until now, in cavitation erosion domain, were aimed to identify the most resistant materials needed to manufacture steam turbine blades, ship propellers, missiles, hydraulic machinery rotors etc. While today, its focusing on studying the solid material behavior at different cavitation stages, and on the metallographic study, a study based on microphotography obtained optically or electronically [3], [4], [5], [7]
In general, the duplex stainless steel presents better mechanical and errosion resistance properties then austenitic ones, but those properties depends on the chemical composition and the applied treatment [6], [8], [9].

By applying the cooling quenching and oven cooling heat treatment to the duplex stainless steel X2CrNiMoN22-5-3, the good mechanical properties (tensile strength, hardness, yield point) are ensured, and the chromium presence of chromium in δ ferrite structure gives a good resistance to intercrystalline corrosion.
By applying gas (ammonia) nitriding thermochemical treatment, the austenitic-ferrite stainless steel, X2CrNiMoN22-5-3, was aimed to achieve a superficial hardness, and a good resistance to fatigue and to cavitation erosion.
Taking into account the research done until now, regarding different ways for increasing the stainless steels cavitation erosion resistance, the present work highlights the effect of the thermochemical treatment applied to the duplex stainless steel compared to the volumic heat treatments regarding the increase in resistance to cavitation attack.
The analysis of the two types of treatments applied to stainless steel X2CrNiMoN22-5-3, was done by comparison with the characteristics of the standard steel - OH12NDL known by all hydraulic turbines manufacturers in Romania, as having very good resistance to cavitation erosion.

2. Researched material. Devices and research method

The researched material are duplex stainless steel, symbolized X2CrNiMoN22-5-3 [6] and standard stainless steel, with primarily martensitic structure, OH12NDL [6].
In the first table, are given the micro hardness HV values, measured on the surface of the specimens, taken from the duplex and the standard steel, which were exposed to the cavitation attack.

Table 1. Micro hardeness, researched in specified states [1], [14]

Steel Symbolisation	Hardness HV1
X2CrNiMoN22-5-3 – recieved state	252
X2CrNiMoN22-5-3 – gas nitiriding state	651
X2CrNiMoN22-5-3 – quenched and oven cooled, state	275
OH12NDL-samples from the spare blades of Kaplan rotor from CHE "Portile de Fier I"	237

According to Table 1 data, Duplex stainless steel, X2CrNiMoN22-5-3, in nitrided state shows the highest micro hardness value compared to other states of the same steel (around 2.6 times higher than the delivered one, and around 2.6 higher than the quenched one), and compared to the standard one (around 2.7 times higher). Considering that this increase is due to nitrogen increase into the surface, results the formation of finely dispersed chromium nitride precipitates [12].
For both steels, were made specimens, that were exposed to cavitational erosion, for 165 minutes, in drinking water of the public grid, at 20-22°C, according to ASTM G 32-2010 standards, regarding the functional parameters of the standar piezoceramic crystal device T2 standard and the standard research procedure [3], [6], [10].
The vibrator device, Figure 1, used in cavitation generation, its owned by Timisoara "Politehnica" University in the Cavitation Laboratory.
Regarding the experiment development procedure, the specimen is mounted on the sonotrode, and immersed up to the squeezing cavity in drinking water, at a temperature of 20-22 ° C, followed by the cavitation test, for a given time (the total duration was 165 minutes divided into 5 minute period (one), 10 minutes (one) and the rest 10 periods, 15 minutes each one). After the cavitation test, the specimen is washed in water and then in acetone. Before weighting the specimen was dried with hot air. The eroded mass is measured with ZaŦklady Mechaniki Precyzyjnej WP 1 analytical scale, which has an accuracy of 10^{-5} grams.
For comparison, the evolution of the surface degradation development under the shock waves impact and the cavitation bubble implosion generated by the microjets, in fig. 2 is given the 90th minute picture of the cavitation attack, and in fig. 3 the picture at the end of the attack.
Because, at the end of the cavitation attack, the samples were analyzed with optical microscope, for highlighting the damage shape, in fig. 3 is presented also the axial splitting procedure (into two

halves), on the diameter ,chosen arbitrarily fixed in resin, and measuring the deepest depths. The parts secured in resin were polished before being microscopically analyzed.

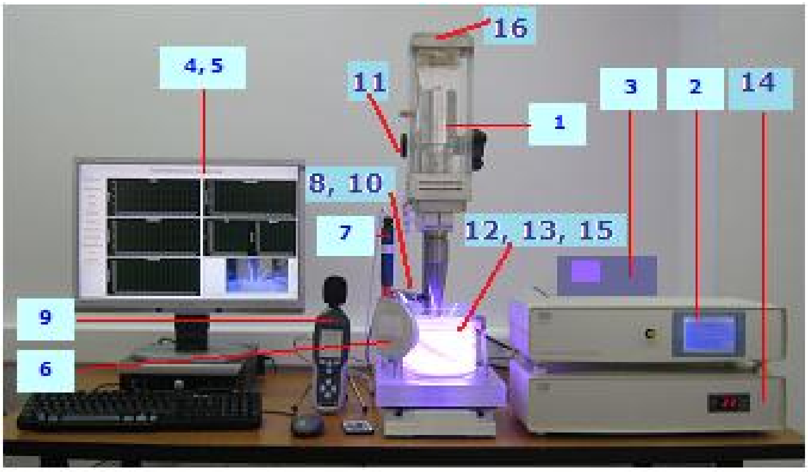
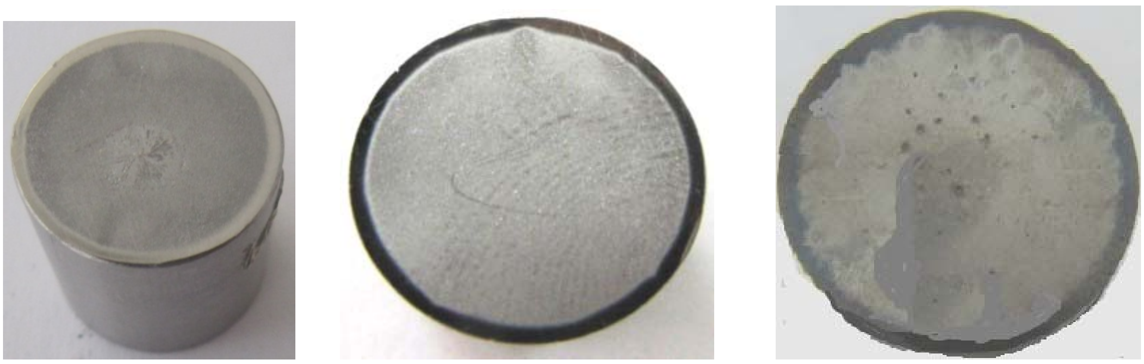


Fig. 1 T2 piezoceramic crystal device
(1. mechanical resonator assembly (20 kHz +/- 200 Hz); 2. ultrasonic generator (240V/50Hz, 20kHz, 500W); 3. PLC data acquisition interface; 4. DELL OPTIPLEX 745 operating system; 5. LCD Monitor PHILIPS; 6. PLANET networking System HD; 7. ProMinent pH-meter; 8. infrared temperature sensor OMEGA Enginnering.Inc; 9. Sound Meter SL-451 VOLTCRAFT; 10. temperature sensor; 11. Mechanical resonator assembly support; 12. Cavitational liquid Flask; 13. Cooling system liquid; 14. Circulation and filtration system for cooling liquid; 15. Flask lightnening system 16. Mechanical resonator assembly ventilation system)

The cavitational experiment was done on three sets of samples: two sets of Duplex stainless steel type X2CrNiMoN22-5-3 and one set of standard steel - OH12NDL.
According to ASTM G32-2010, each set of samples contained three samples.
The first investigated set of steel specimens, was X2CrNiMoN22-5-3, containing the specimens heat treated by quenching at a temperature of 1060 ° C for 30 minutes, followed by oven cooling. The second set of steel specimens, was the one treated thermochemical in nitriding gas environment (at a temperature of 520 ° C, in ammonia). The heat treatment was done in Timisoara “Politehnica” University, in the Laboratory of Materials Science, and the thermochemical one was done in S.C. Duroterm S.A. Bucharest.



a. Standard (OH12NDL) b. Quenched c. Nitrided in gas

Fig.2 Pictures from 90th minute of surfaces exposed to cavitational attack

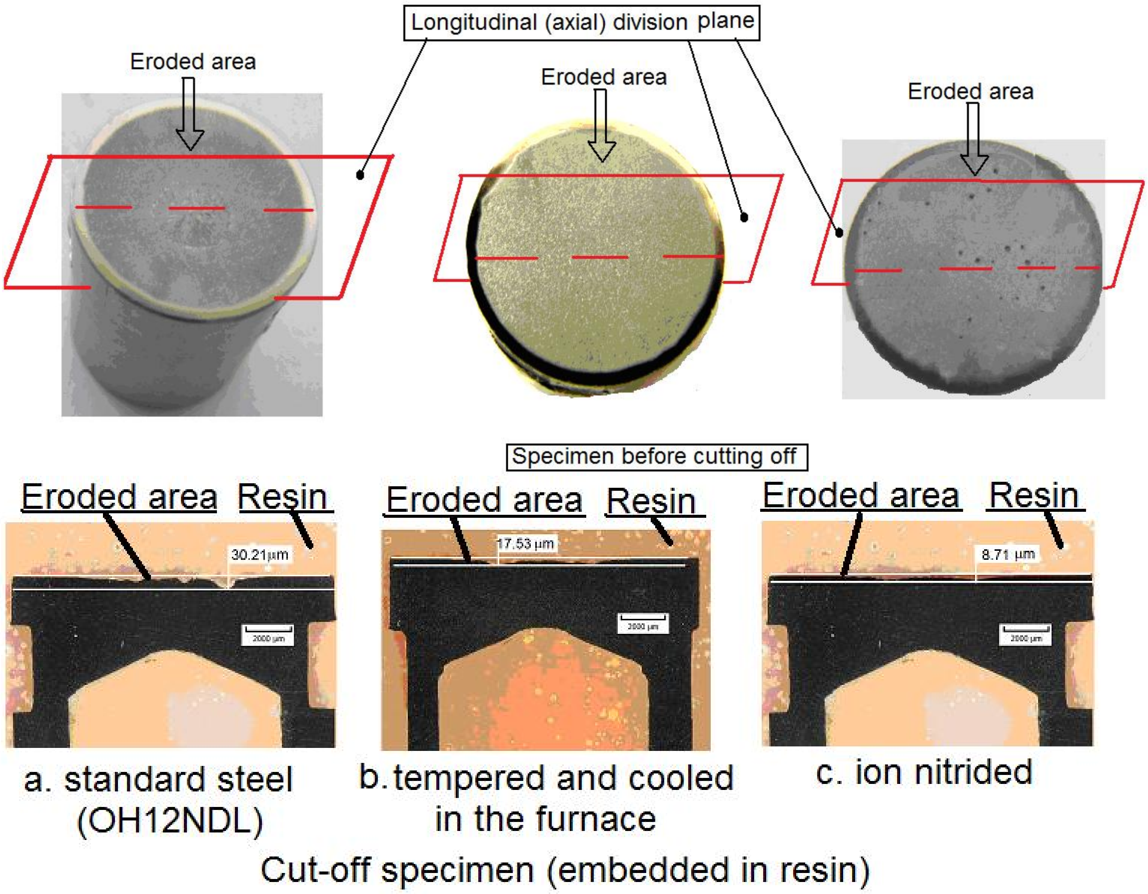


Fig.3 Pictures of the eroded surfaces after 165 minutes of cavitation test
(Specimens preparation for microscopic analyze)

From Figure 3, the pictures with the specimens secured in resin, it can be observed that the penetration depth of the specimens heat-treated (17,53 μm) and thermochemical treated (8,71 μm) are significantly lower than the one resulting from the standard steel specimen (30,21 μm), which shows the beneficial effect of the treatment regarding the cavitation resistance.

3. Experimental results

In figure 4, are presented the specific erosion curves, constructed based on cumulative mass losses, obtained after weighting the cavitated specimens. As it can be seen, the nitrided specimens, presents a greater resistance to cavitation erosion, therefore the losses were much lower during the entire period of attack. This happens, mainly, due to steel hardness obtained after being nitriding treated in the gas.
According to figure 4 diagram, the most mass losses at the end of cavitation erosion test, were obtained for the standard steel OH12NDL, followed by stainless steel Duplex (X2CrNiMoN22-5-3) heat treated by quenching. These results confirms that by applying a single heat treatment, quenching, the steel cavitation erosion resistance increase; because by quenching acquires a martensitic structure on deep area, having a higher hardness and a better cavitation resistance.

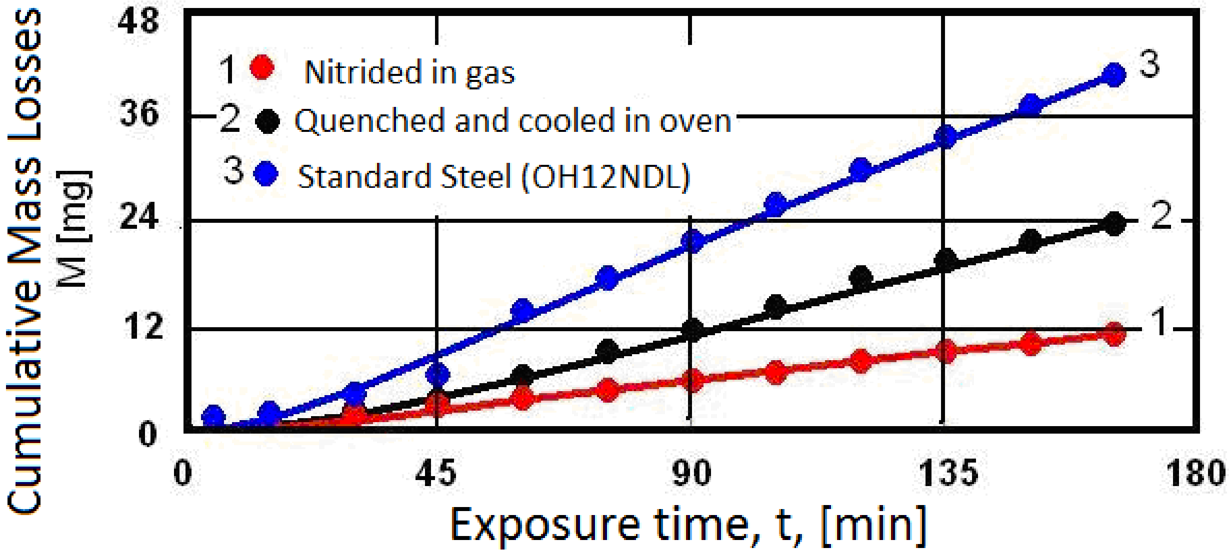


Fig.4. (Cumulative) Weight losses variation according to exposure time

From the losses recorded at the end of 165 minutes, results that, related to the standard steel, the duplex steel X2CrNiMoN22-5-3 diminish its weight lost through erosion with almost 41.7% by quenching with air cooling, and with almost 73,5 % by gas nitriding (ammonia). Also it can be observed the thermochemical treatment provides superiority compare to the thermal one because the mass losses decreased with almost 54.5%.
Figure 5 presents the evolution of erosion rate curves of Duplex stainless steel, the two states, compared with the standard steel OH12NDL.

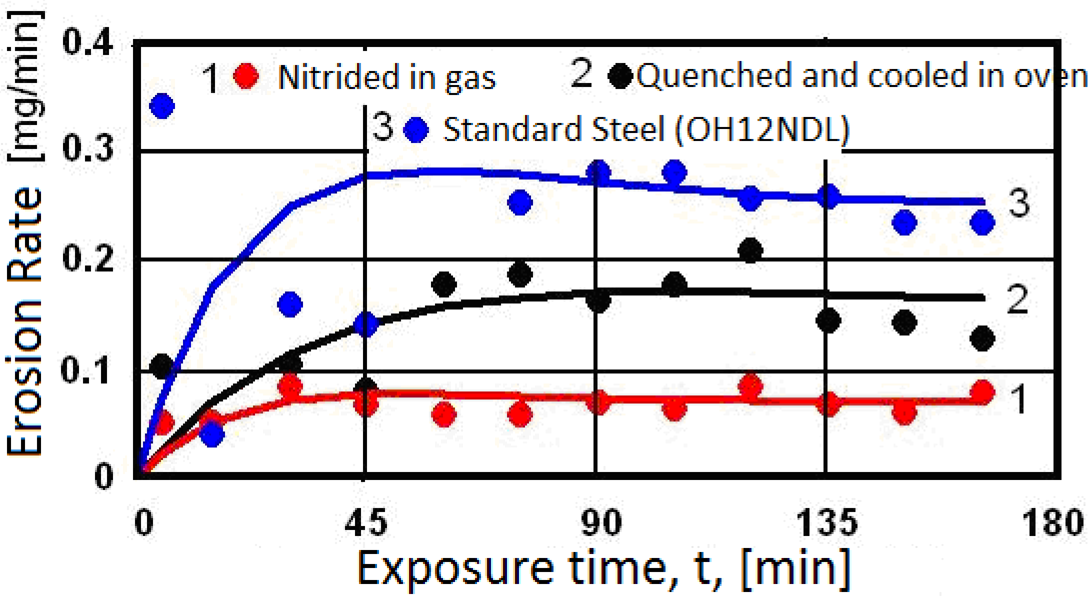


Fig.5. Erosion rate according to the exposure time

It was found that, by applying nitriding thermochemical treatment, the stainless steel X2CrNiMoN22-5-3 was recording a significant decrease of the erosion rate, created by micro jets in the body, (around 0,24 mg/min) compared with the same steel heat treated by quenching (around 0,066 mg/min), but both of them record a lower decrease then the standard steel (around 0,164 mg/min).

Regarding the resistance increase, taking as reference the value to which the speed tends to stabilize (fig.5), results that by gas nitriding, the researched duplex steel increases its resistance to cavitation with around 60 % compared to the state obtained by quenched and cooled in the oven, and approximately 72,5% compared to the standard steel.
During the same time, it can be also seen the quenching and oven cooling effect, resulting in a large increase of the cavitation erosion resistance. Compared to standard steel, the erosion rate increases with almost 32 %.
Therefore both treatments are advisable to be used, especially where duplex steel X2CrNiMoN22-5-3 is used to manufacture the parts used in cavitation.
In the fig.6 diagram are compared, the mean depths of erosion, resulted by approximating the data points from fig. 4, with the maximum values measured in the axial sections fig.3.

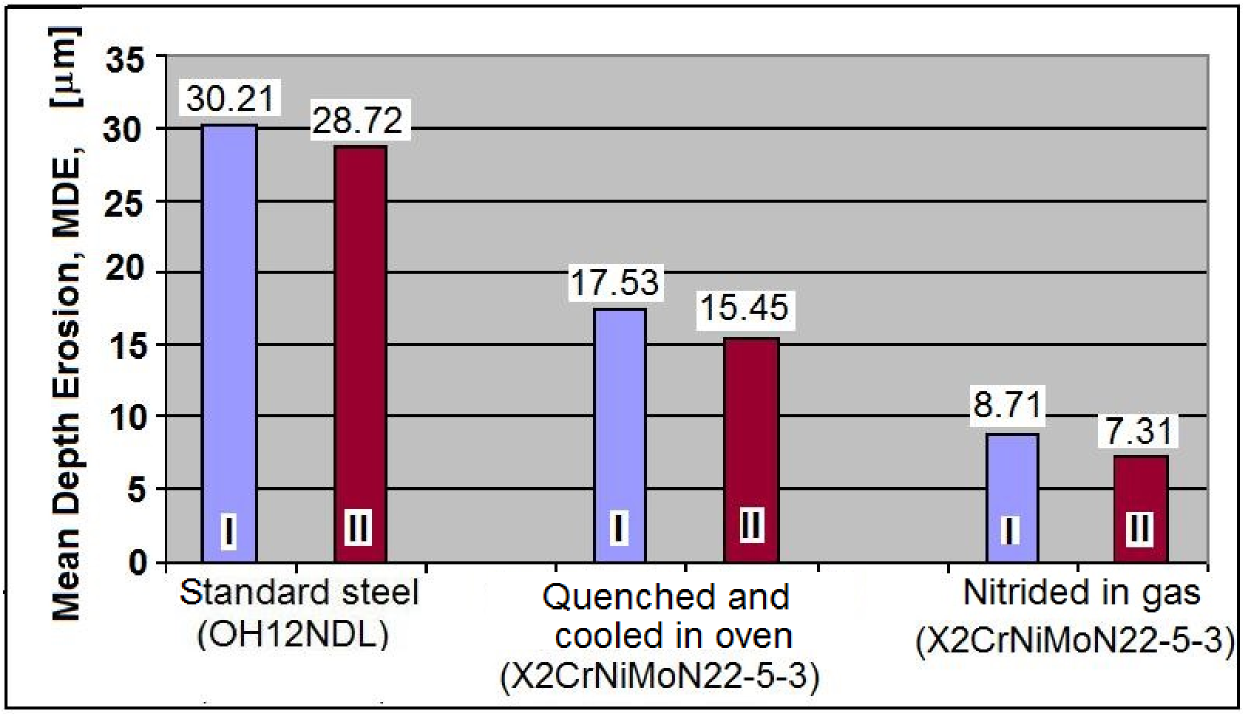


Fig. 6 Mean Depth Erosion
I – Maximum measured value in the cut – off section performed according to fig.3
II – Average of the cumulative mass losses at the end of cavitation attack (fig.4)

From fig. 6 it can be distinguished, the differences between the depths resulted from the cumulated mass losses and the measured ones, in an arbitrary cut-off section, as the one presented in fig.3. These differences are natural, but not especially in this form, and present that:
- The cavitation erosion is not a uniform process through the entire exposed area, depending on the expelled grain size, structural defects, uniformity of the surface mechanical properties, grain size, etc.
- The cumulative depths presented in fig.4 are average values, obtained by calculation, where the size of the area damaged by cavitation its involved, material density and obviously the measured mass.

4. Conclusions

Important conclusions, regarding the aimed purpose by the results presented in this paper, are given by the comparison of the cavitation resistance of duplex steel X2CrNiMoN22-5-3 in the two states, with the one of the standard steel OH12NDL, a steel considered with good resistance to cavitation.

- Using the gas (ammonia) nitriding thermochemical treatment, on the parts that operates in intense cavitation flow conditions, is recommended, because is giving an increase of hardness which provides a large increase in resistance to cavitation attack.
- Applying the volumic heat treatment, as the quenching with oven cooling, remains the classical method through which the cavitation resistance of duplex stainless steels can be improved.
- Regarding the cavitation resistance improvements of X2CrNiMoN22-5-3 duplex steel, the thermochemical treatment efficiency is higher than the quenching and oven cooling one..

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