GAS NITRIDING AND CAVITATION EROSION RESISTANCE OF X5CrNi18-10 STAINLESS STEEL

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Abstract

The harmful effect of cavitation is the erosion of the material. Although there are many studies on improving the mechanical properties of the material in order to increase resistance to cavitation so far none has defined the optimal solution for complete protection against this type of wear. New methods aimed at increasing resistance to cavitation erosion use surface hardening techniques. One of them is the gas nitriding, which ensures a significant increase of the surface layer hardness. This aim of present paper is highlighting the behavior and the resistance acquired by X5CrNi18-10 austenitic stainless steel, nitrided in gas. This steel is used both for manufacturing and repair works of details used for equipment subjected to intense cavitation. The cavitation erosion resistance is put into evidence both by analyzing the images of the eroded surfaces by optical and electronic microscopy, as well as by comparing the specific characteristics curves of the steel subjected to solution treatment at 1100 °C with cooling water and the standard OH12NDL steel, which is known for good resistance to cavitation attack, in field conditions.

Keywords: Austenitic stainless steel, gas nitriding, cavitation erosion, mean depth erosion, erosion rate

1. INTRODUCTION

Inexistence of technologies through which can be developed materials that cannot be destroyed by cavitation, led researchers to resort to different methods of protecting surfaces exposed to cavitation [1]. Among these are methods of increasing the hardness of the surfaces exposed to the impact with micro jets and shock waves, generated by the implosion of cavitation bubbles. Such a method is nitriding in gaseous medium, which causes an important increase of surface hardness, leading to the reduction of cavitation erosion, and thus increasing the lifespan of the details subjected to cavitation. In the construction of hydro-mechanical equipment there are a number of components highly stressed to cavitation (blades and runners of turbines, hydraulic pumps impellers, navy propellers, butterfly valves, etc.), which depending on the periodical repair works determines financial loss increases [3]. The practical experiments and results of research in specialized laboratories [1, 4, 5] shows that the stainless steels, due to the mechanical and structural features, are materials that confer an important resistance to cavitation, which can be substantially improved by volume heat treatments and by thermo-chemical treatments such as nitriding in gaseous environment. Such is the austenitic stainless steel is X5CrNi18-10, whose resistance and behavior to cavitation can be improved by nitriding in gaseous environment. Whereas currently the fastest way to check in laboratories the material resistance to cavitation is the testing on vibrating devices, known for their intensity of destruction, this steel was tested in a standard vibratory device with piezoelectric crystals in the Timisoara Polytechnic University Laboratory of Cavitation.

2. MATERIAL AND TREATMENTS

The material on which have been performed cavitation test is the stainless steel with preponderant austenitic structure (88% austenite + 12% ferrite), subjected to thermo-chemical nitriding treatment in gas, for 40 hours. Nitriding in gas - is a thermo-chemical treatment for nitrogen enrichment of the superficial layer, resulting in the formation of nitrides giving a significant hardness increase [2, 5]. The treatment was carried out in accordance with cycle diagram given in **Figure 1** and consisted in introducing the samples in an oven heated at 560 °C with a controlled atmosphere of nitrogen and maintained there for 40 hours. Through this technique, the nitrogen found in an atomic state in the furnace atmosphere, penetrated by diffusion into surface layers of samples, being chemically combined with both the iron and the alloying elements, giving rise to nitrides. The cooling was done at the beginning in treatment furnace in an ammonia atmosphere till 150 °C, after which it was continued in air. Before the gas nitriding, the surfaces of specimen exposed to cavitation, were rectified to Ra = 3.2 μm roughness.

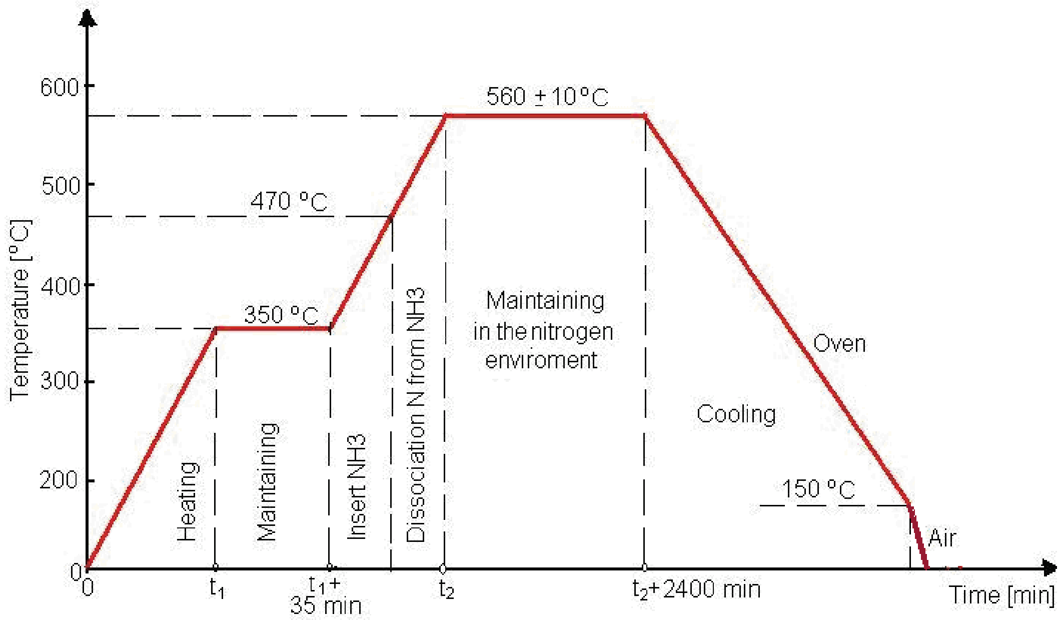

Figure 1 The diagram of the gas nitriding thermo-chemical treatment

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**. Because the assessment of the vibratory cavitation resistance is achieved by comparing the specific parameters of cavitation erosion, with the stainless steel OH12NDL, [5] (84 % martensite + 16 % ferrite), in the following two tables are presented also the characteristics of this steel. The steel structure was established with the Schäffler diagram using chrome-nickel equivalents [5]. All the cavitation erosion tests respect the ASTM G32-2010 Standard [6].

Table 1 Chemical composition [wt. %]

Steel	C	Cr	Ni	Mn	Si	Cu	W	P	S	Fe
X5CrNi18-10	0.046	17.95	8.11	1.46	0.89	0.27	0.16	0.024	0.019	Bal.
OH12NDL	0.1	12.8	1.25	0.4	0.3	0.9	-	0.09	0.03	Bal.

Table 2 Mechanical characteristics

Steel	TS (tensile stress) [MPa]	YS (yield stress) [MPa]	HB [-]
X5CrNi18-10	550	226	183
OH12NDL	650	400	225

The evaluation of cavitation resistance, conferred by the nitrided layer, is achieved by comparing the results obtained on samples of the same steel hardened by quenching (heated at 1100 °C temperature, maintained 25 minutes at this temperature and afterward cooled in water).

3. EVALUATION AND INTERPRETATION OF RESULTS

3.1. Microstructural investigations

In **Figure 2a** there is presented the microstructure in cross section of the gas nitrided sample and in **Figure 2b** a frontal view of the eroded area. For comparisons in **Figure 3** are given the similar pictures for the samples subjected to a quenching heat treatment.

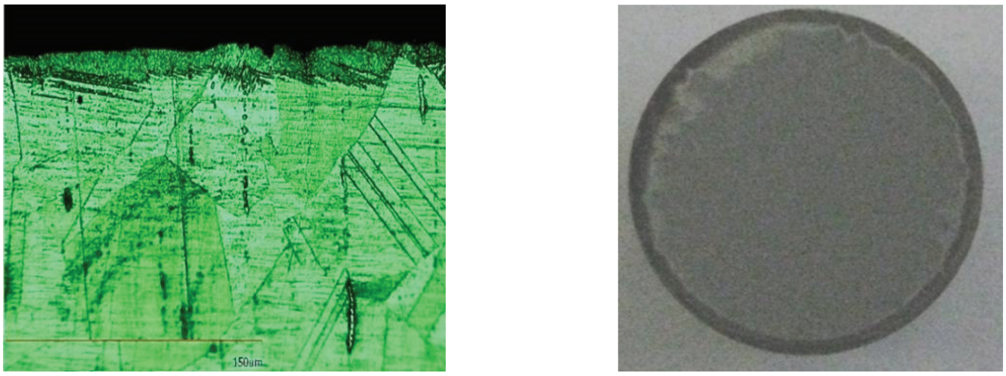

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Figure 2 Damages caused to the surface exposed to cavitation attack for 165 minutes (after gas nitriding): a) optical microscopy of a cross section; b) view of the eroded area

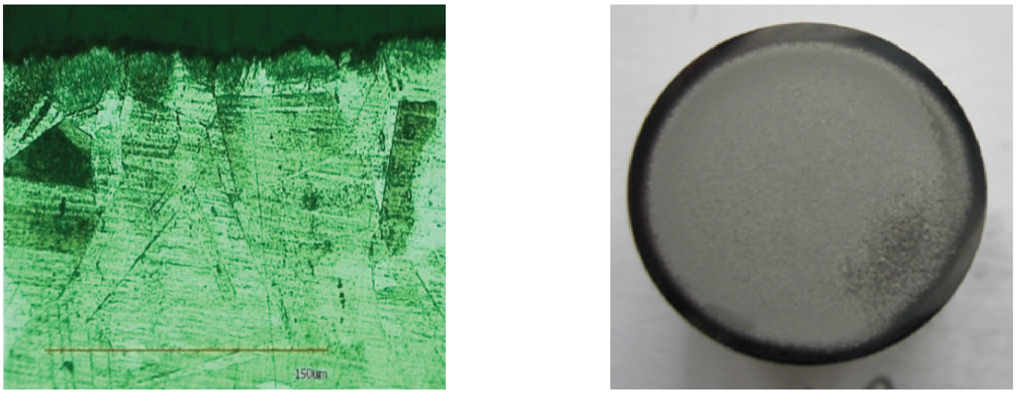

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Figure 3 Damages caused to the surface subjected to cavitation attack for 165 minutes (hardening to 1100 °C / cooling in water): a) cross section optical microscopy; b) view of the eroded area

From both pictures result that in the core of sample there is a microstructure composed of twinned annealed austenite, a certain proportion of δ ferrite and small quantities of carbides, $M_{23}C_6$. The surface degradation of the nitrided samples is uniform (**Figure 2**), but that of hardened sample for commissioning solution, the erosion is initiated mainly on the grains boundaries (**Figure 3**).

3.2. Micro hardness testing

Figure 4 presents hardness variation on the cross section for the nitrided samples. The presence of chromium as a main alloying element, forms nitrides and determine a marked increase in the hardness values till to approx. 860-880 HV0.05. The depth of the nitrided layer has a value of approximate 0.14 mm and is defined as the distance from the surface to the point at which the core hardness exceed with 50 HV those of the base material.

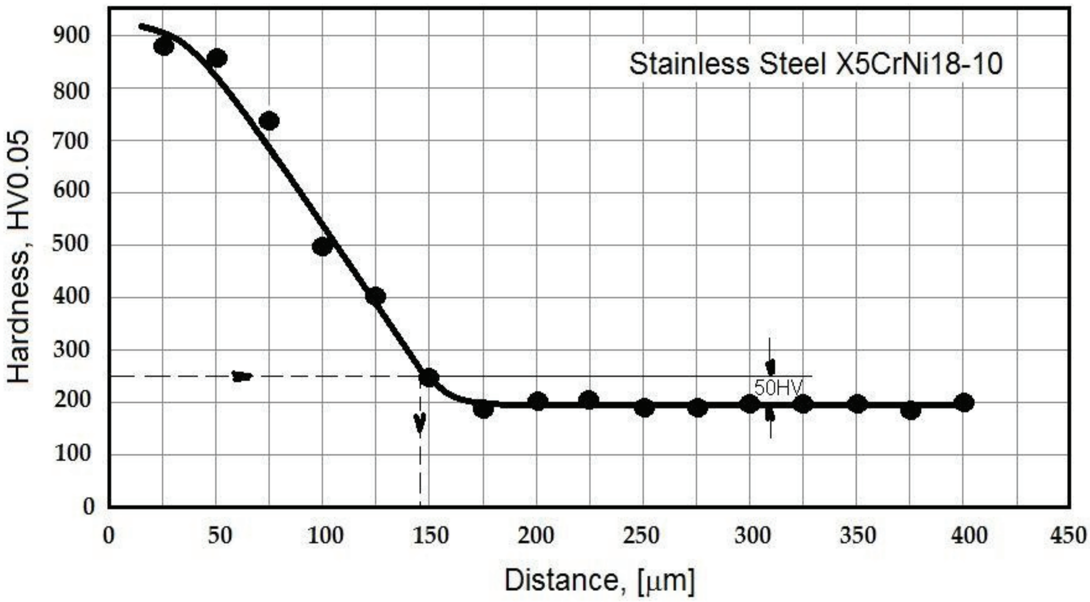

Figure 4 Curve of hardness gradient on cross section of nitrided layer

3.3. The research of behavior and resistance to cavitation

The cavitation erosion experimental program was done on the vibratory device with piezoelectric crystal in Timisoara Polytechnic University Cavitation Laboratory respecting the ASTM G32-2010 Standard [6] as well as the laboratory customs resulting from an experience of over 70 years of research. The experimental results, expressed by the variations in time of cumulative mass losses M(t) and erosion rates v(t) are shown in **Figures 5, 6.**

From the two diagrams shown in **Figures 5, 6**, regardless of the parameter taken into consideration cumulative mass losses or erosion rate, at the end of the test (165 minutes) it results that the nitrided layer confers a superior resistance against both comparisons materials. For the standard steel OH12NDL the increase is over 88 % and for the samples subjected to hardening heat treatment for commissioning solution the increase is over 60 %. These increases against cavitation erosion will have as effect an increase of the running life. As a consequence, we recommend the use of thermo-chemical process of gas nitriding to steels, with structures similar to those investigated for the details heavily affected by cavitation.

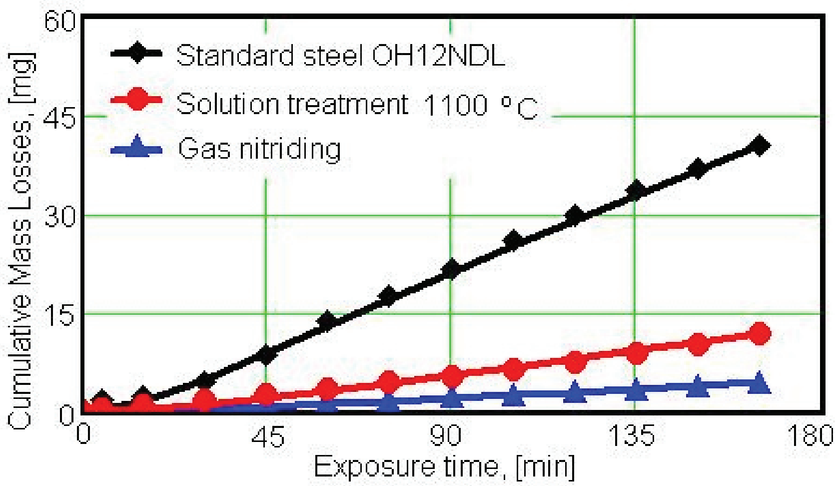

Figure 5 Variation of cumulative mass losses with exposure time

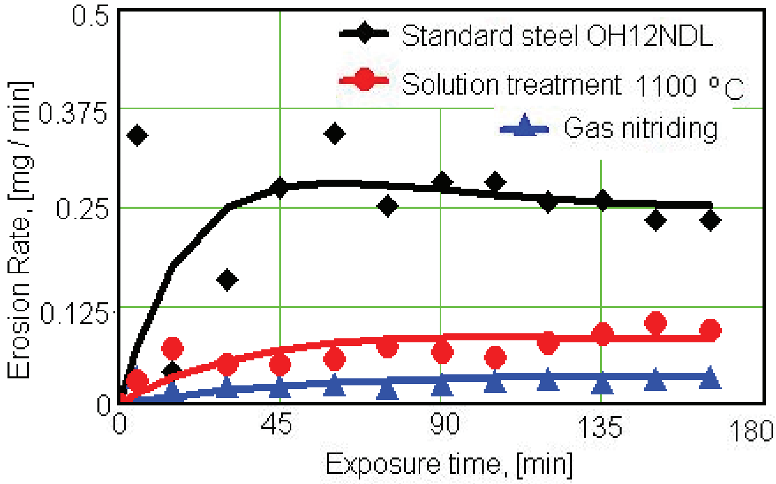

Figure 6 Variation of erosion rate with exposure time

3.4. Measurements of surface roughness

In **Figure 7** are given the average values of roughness Ra, measured on three directions upon the three specimens subjected to cavitation samples. The uniform erosion on the exposed surface appears as a result of uniform hardness distribution.

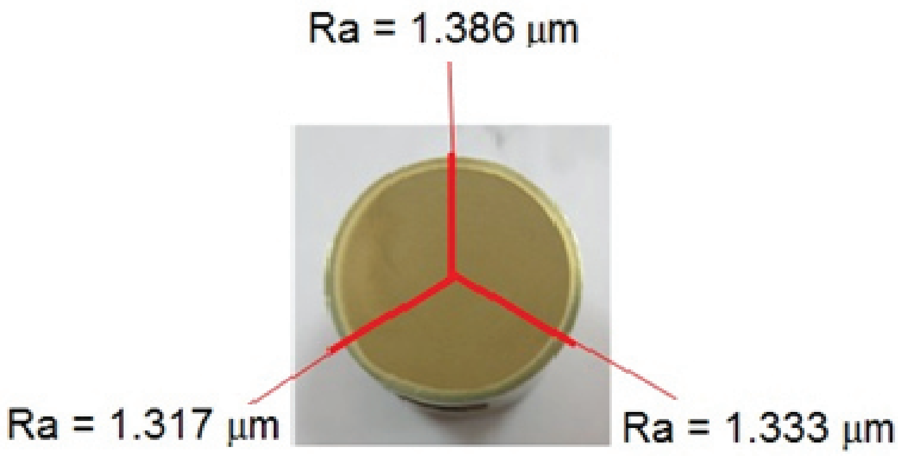

Figure 7 Measuring scheme of Ra roughness, with the Mitutoyo SJ210 device, for specimen surface subjected to cavitation for 165 minutes

4. CONCLUSION

The application of the thermo-chemical treatment of gas nitriding to stainless steels made details, which work in cavitation, having austenitic structure, such as X5CrNi18-10 is beneficial, leading to important increases at cavitation erosion resistance. Compared with the traditional steel OH12NDL frequently used in manufacturing hydraulic turbine blades, where the hydrodynamic regime of cavitation is intensely destructive the erosion rate can be reduced by about 8 times.

Although the volume heat treatment hardening for commissioning in solution is the procedure mostly used for parts that operating in highly destructive cavitation regimes the increase resistance to erosion cavitation with over 60 % in our tests, obtained by using nitriding in gaseous environment, recommend this process as an excellent solution to extend the running duration in heavy cavitation conditions.

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