DURATION OF THE AUSTENITIZATION AND THE CAVITATION EROSION RESISTANCE TO STAINLESS STEEL X5CrNi18-10

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Abstract

The cavitation erosion resistance of the stainless steel was studied with ultrasonic vibration equipment, at a frequency of 20 kHz and oscillation amplitude of 50 µm. Varying the holding duration at the constant heating temperature, causes changes both in terms of the not dissolved austenite, chemical compounds (carbides, inter-metallic phases), phases proportion, as well as in the size of the crystal grains.

The cavitation test results were compared with those obtained by the standard OH12NDL steel used in the manufacturing of hydraulic turbine blades Kaplan of the Power Plant Iron Gates I, Romania. Optical and electronic metallographic examinations and hardness tests have shown, that by heat treatment is obtained a fine and homogeneous microstructure with a high resistance to plastic deformation which provides an improvement in the cavitation eroosion behavior.

Keywords: Cavitation erosion, austenitic stainless steel, heat treatment duration

1. INTRODUCTION

Regardless of their structure, the lifetime of stainless steels subjected to cavitation, [1], [2], [3], can be increased by volume heat treatments. These treatments, depending on the temperature maintenance and the cooling mode, leads to structural transformation, which through - a proper routing, can increase the resistance to cavitation erosion. The present paper presents researches results on cavitation erosion, upon on the austenitic stainless steel X5CrNi18-10, subjected to three different regimes for the quenching (constant temperature 1050 °C), maintenance time 5, 25 and 50 minutes in cooling water.

2. TESTED MATERIAL AND THERMAL TREATAMENT

The investigated material is stainless steel X5CrNi18-10 recommended to manufacture butterfly valves discs, for hydraulic turbine adduction pipes with medium and high falls. Also, electrodes from this material are commonly used to repair the cavitations eroded areas for hydraulic turbine blades and runners [4], [5], [6], [7]. [8].

The values of main mechanical properties, provided by the manufacturer Inox Service Hungary as well as those measured are:

- Indicated by manufacturer: R_m = 500-700 MPa, $R_{p0.2}$ = 196 MPa, Hardness =183 HB;
- Determined in the laboratory: R_m = 550 MPa, $R_{p0.2}$ = 226 MPa, Hardness =218 HB.

The chemical composition (wt %), prescribed by the manufacturer is : max. 0.07 % C; 17.5-19.5 % Cr; 8.00-10.50 % Ni; max. 2.0 % Mn; max. 1.0 % Si; max. 0.045 % P; max. 0.015 % S; max. 0.11 % N; the remainder is Fe. The values determined in the laboratory 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; Fe rest.

Since cavitation erosion resistance performance are assessed by comparison with the Russian reference steel OH12NDL, used on a large scale for manufacturing hydraulic machineries in Romania we will give also the mechanical properties and chemical composition of this steel [5],

- mechanical properties: R_m = 650 MPa, $R_{p0.2}$ = 400 MPa, Hardness = 225 HB;
- chemical composition (wt %): 0.1 % C; 12.8 % Cr; 1.25 % Ni; 0.4 % Mn; 0.3 % Si; 0.9 % Cu; 0.09 % P; 0.03 % S; Fe rest.

Experimental researches of cavitations have been carried out on three sets of specimens heat treated by quenching for release in solution, in which the temperature for obtaining austenite was kept constant but the maintenance times was varied (5 min, 25 min and 50 min), as can be seen in the cycle diagram (**Fig. 1**).

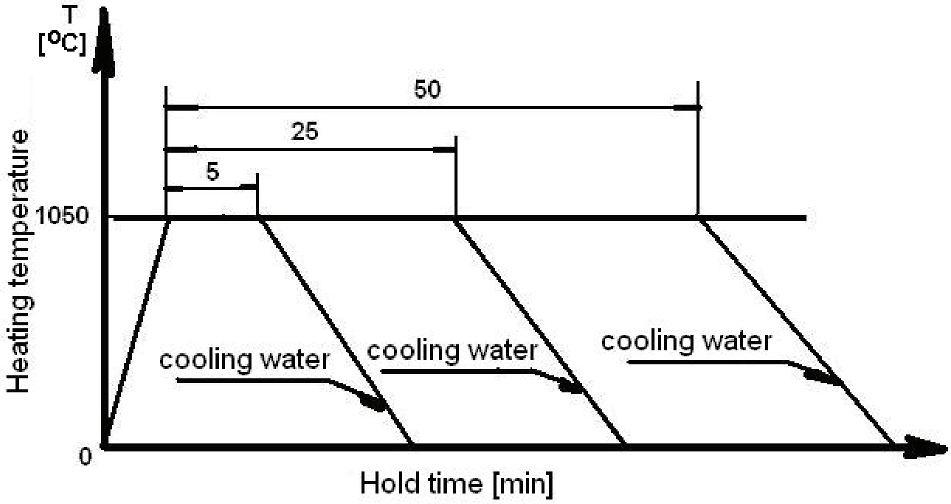
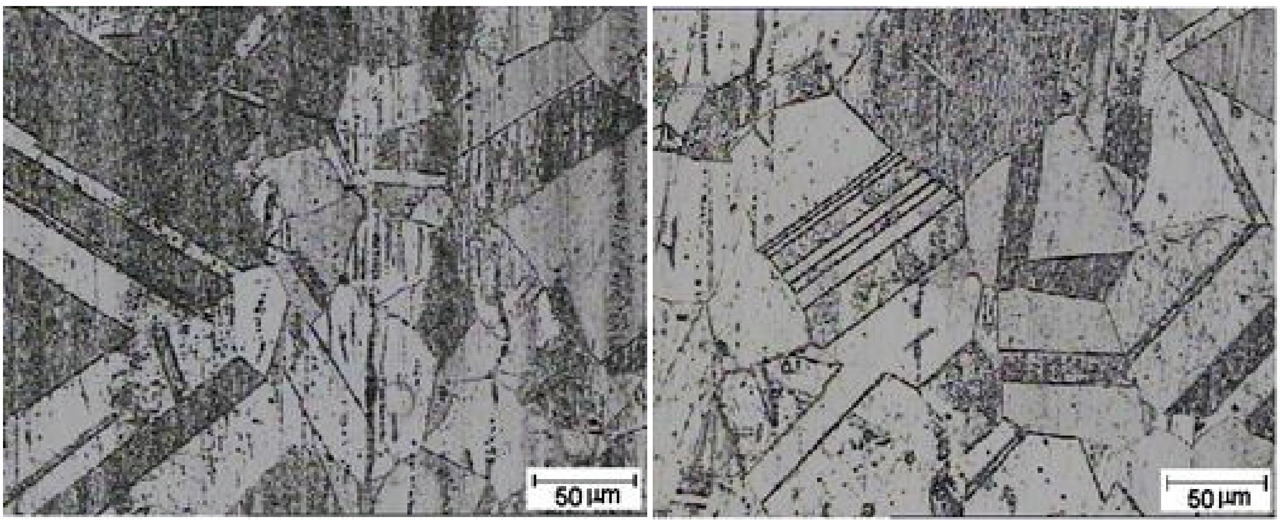
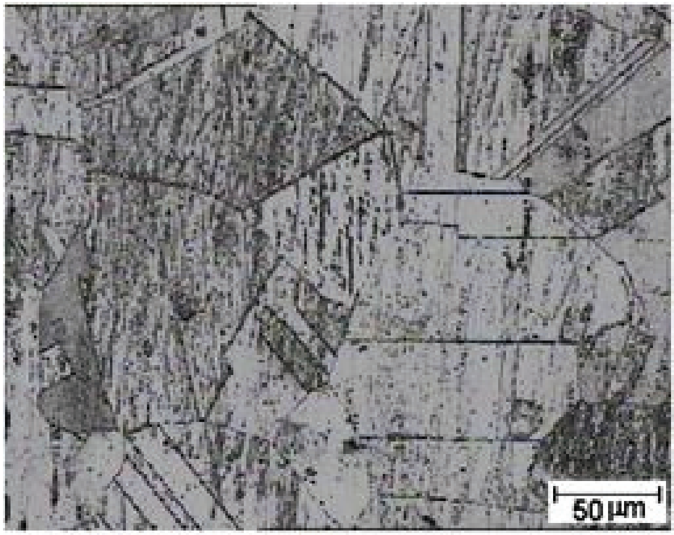


Fig. 1 Heat treatment cycle diagram

The analyzes carried out with an optical microscope have shown that by increasing the maintenance times, at 1050 °C increase the grain size is from 35 µm to 60 µm (**Figs. 2 - a, b, c**) as a result of increasing the diffusion phenomena of the carbon and alloying elements.



- a - - b -



- c -

Fig. 2 Microstructure of austenitic samples maintained at constant temperature but having different time maintenance: a - 1050 °C / 5 min and water cooling; b - 1050 °C / 25 min / water; c - 1050 °C / 50 min / water

Laboratory measurements showed that for a maintenance duration of 5 minutes was obtained an average hardness of approx. 225 HV1, for 25 min approx. 198 HV1 and for the 50 minutes, approximate 187 HV1.

Because this mechanical property has an important influence upon the surface resistance against the micro jets and shock waves generated by the implosion of cavitation bubbles, [3], [8], [9], [10], [11] it results the need to correlate the heat treatment parameters such as heating temperature, duration of maintenance and cooling rate, in order to increase the resistance to cavitation attack.

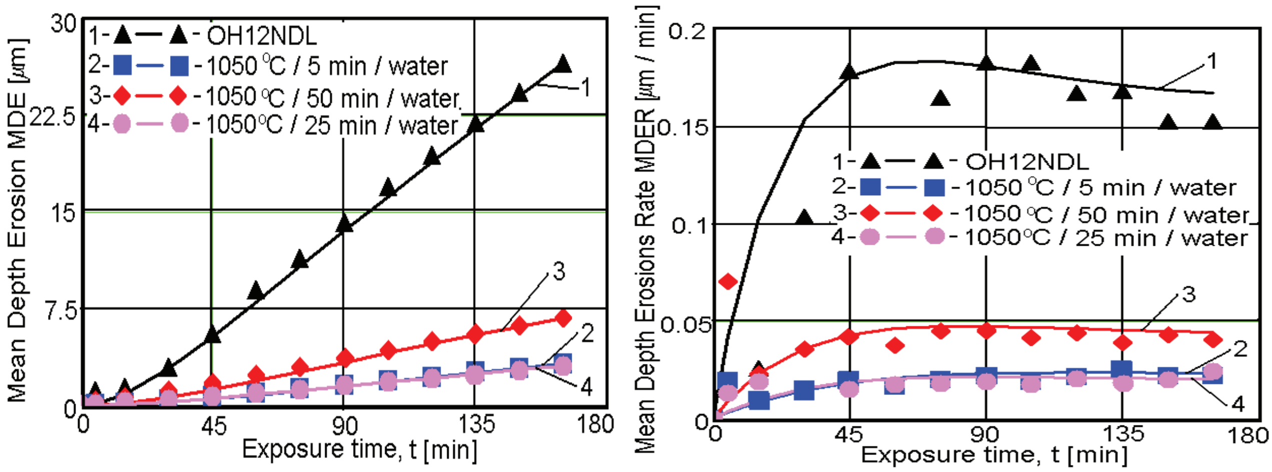
3. APPARATUS AND TEST METHOD

The cavitation erosion resistance was tested in the vibratory device T2 [1], [12], [13], with piezoelectric crystals, in the Timisoara Polytechnic University Cavitation Laboratory, following the procedures defined by the ASTM G32-2010 Standard [2]. In addition to the procedures defined by ASTM G32 Standard were respected also the laboratory customs resulting from over 70 years of experience, in this field. They relate to the manner of preparation, cleaning/washing and storage of the experimental specimens, mass loss measurement, eroded surface analyze with optic and scanning electron microscopes, as well as the total duration of cavitation attack, limited to 165 min and divided into 12 intermediate periods of 5, 10 and 15 minutes [5], [8].

It should be mentioned that, during tests, the running parameters of the device that determine the intensity of cavitation erosion were strictly maintained at the values prescribed by ASTM standards (vibration frequency = 20000 ± 20 Hz, double vibration amplitude = 50 micrometers, temperature of the distilled water = 21 ± 1 °C, electronic ultrasonic generator power = 500 W). The diameter of the specimen surface exposed to cavitation attack is 15.8 mm, imposed by ASTM G32 Standard. Following the experimental customs, for each heat treatment there were investigated three specimens.

4. EXPERIMENTAL RESULTS. ANALYSIS AND DISCUSSION

The evaluation of cavitation erosion resistance was realized by comparing the experimental curves resulted for the analyzed specimens with those obtained for the standard OH12NDL stainless steel, with martensitic structure [5]. The diagrams are shown in **Fig. 3**, which present both the mean values experimentally obtained and their mediation curves. There are given two types of diagrams for the cavitation erosion evolution: mean depth erosion MDE(t) and mean depth erosion rate MDER(t). The mediation curves were obtained using the Bordeasu procedure [5].

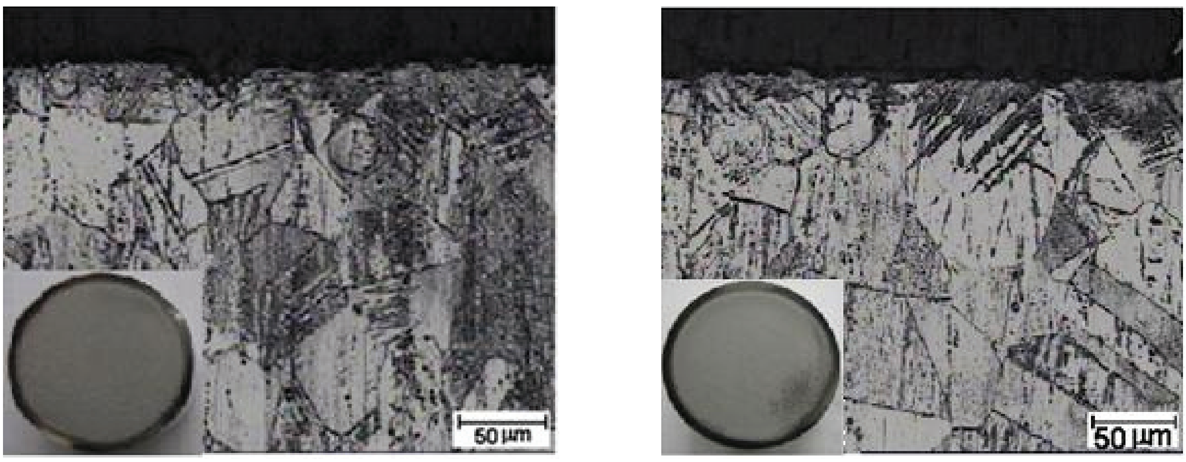


- a - - b -

Fig. 3 Cavitation erosion specific curves: a - Mean depth erosion penetration against exposure time; b - Mean depth erosion rate against exposure time

Comparison with standard steel OH12NDL, considered with good resistance to cavitation, after 30 years of field running [3], [5], [9], shows that thermal treatment for release in solution, offers a substantial increase resistance in the cavitation erosion. In comparison with the reference material, the growth of the penetration erosion rate MDER (**Fig. 3b**) for 25 minutes maintenance at 1050 °C is about 8.35 times smaller, for 5 minutes maintenance is about 7.26 times smaller and for 50 minutes maintenance is about 3.80 smaller. We believe that these increases in cavitation erosion resistance are achieved as an effect of a better balance between the mechanical properties and the hardness increase which does not overcome the values which the material become brittle [6], [7]. A good effect has also the chemical composition (especially the lesser sulphur and the greater proportion of nickel, both increasing the resistance to cavitation erosion).

It also was found that, regardless of the specific curve, the value of the cavitation erosion for the maintaining times 25 and 5 minutes are without great significance. This behavior is put into evidence both in **Fig. 3** (characteristic curves) and **Fig. 4** (aspect of the final eroded surface). The explanation lie in the mechanism of heat treatment transformation which gives a greater resistance as can be seen in **Fig. 4**.



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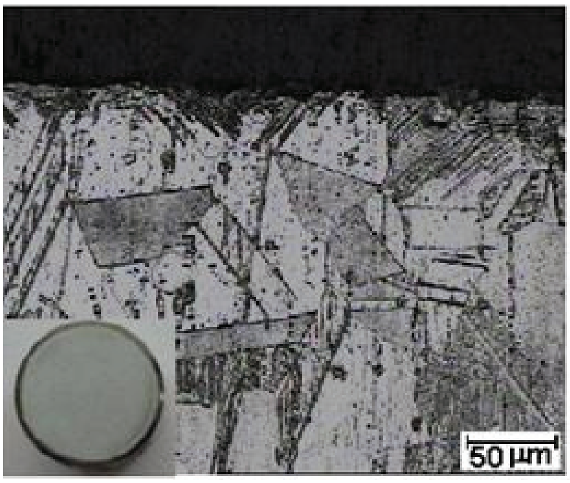

- c -

Fig. 4 The macrographic and the optical micrograph of the eroded surfaces, after 165 minutes of cavitation erosions, subjected to three different regimes of heat treatment by maintenance at constant temperature by 1050 °C, for : a - 5 min, b - 25 min, c - 50 min and cooling in water

The images in **Fig. 4** show that regardless of the duration of maintaining the entire exposed surface erosion is a uniform one, with a lower depths developments after 25 minutes maintenance (**Fig. 4b**) and is higher for the maintenance of 50 minutes (**Fig. 4c**). However, there appears also a mechanical hardening in the surface layer with a thickness of 60 till 90 µm, caused by the mechanical action of cavitation bubble implosion causing martensitic transformations.

The slightly different behavior are explained by the differences emerged in the formation of chromium carbides and inter metallic phases, as well as by changes in the sizes of the crystal grains. It is estimated that both phenomena determine the differences of the Vickers hardness, affecting cavitation resistance, as is shown in the curves of **Fig. 3**.

5. CONCLUSION

The results of the presented research show that austenitic steel X5CrNi18-10 hardened by a heat treatment for release in solution at 1050 °C and cooled in water increases its resistance to cavitation erosion, well above the reference martensitic steel OH12NDL, used a long time for manufacturing hydraulic turbine blades and runners.

The heating temperature with a maintaining time of 25 minutes followed by cooling in water compared with the maintenance times of 5 and 50 minutes provides the greatest increase against cavitation erosion, due to the difference in the carbides of chromium solution release, inter metallic phases and the change of crystalline grain size.

The cracks initiated by the cavitation bubble implosion are located mainly in the crystalline grain boundaries and along macles, and the degradation mechanism of it is the ductile fracture.

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