PRIMARY AND SECONDARY AGING EFFECT ON THE CAVITATION EROSION BEHAVIOR OF 17-4 PH STAINLESS STEELS

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Abstract

Austenitization temperature of these steels can be used as a control measure of the transformation characteristics. Paper analyses the cavitation behaviour of a steel subjected to solution treatment at a lower temperature (950 °C), after which a primary aging at 700 °C and a tempering at 450 °C, were applied. The cavitation tests were conducted on a vibratory facility with piezoelectric crystals, in conformity with the prescription given by the ASTM G32-2010 Standard. The variation curves of mass losses and their speed during the test period, along with the hardness measurements and metallographic examinations, explain the degradation mechanism of the surface at the impact of the cavitation bubbles from the hydrodynamic field.

Keywords: 17-4 PH stainless steel, cavitation erosion, characteristic curves, microstructure

1. INTRODUCTION

The degradation by cavitation erosion of hydraulic machinery components is manifested by a reduction of their efficiency since it is accompanied by instability of the fluid flow and the by appearance of noises and vibrations. Because of these reasons, we can ascertain an increase of the maintenance operations frequency and its cost of component reshuffling with consequences related to the reduction capabilities of energy production to hydraulic plants.

The 17-4 PH stainless steels possess high mechanical resistance characteristics, an excellent corrosion resistance and a good welding behaviour, being widely used in the execution of hydraulic turbine blades [1, 2, 4-6]. However, the impact generated by the cavitation bubbles affect the lifetime of these machine parts.

One method to increase the resistance to cavitation erosion of these steels is established by the application of some volume heat treatments. For a given chemical composition of such steel, the temperatures of the critical points, Ms and Mf, are considerably influenced by the austenitizing temperature to quenching, by the aging process of the austenite up to approx. 700 °C and by the cold forming processing [3, 4].

This paper appeals to one of these methods of producing phase and structural transformations which may result to higher resistance against cavitation erosion.

2. EXPERIMENTAL PROCEDURE

The casted and peeled bars (Φ50 x 500 mm) from the steel (see chemical composition in **Table 1**) were preliminary annealed, afterward homogenized and tempered at high temperature. Transposing the values of chromium equivalent and nickel equivalent on the Schäffler diagram [2, 3, 4] used to define the nominal characteristic point, resulted that the microstructure of the casted steel consists of austenite + martensite + 10 % of δ - ferrite.

Tabel 1 Chemical composition of the researched steel (wt. %)

Additional and alloying elements											
C	Si	Mn	Ni	Cr	Mo	Al	Co	N	Cu	P	S
0.10	0.50	1.56	4.12	15.57	2.11	0.58	2.04	0.046	0.18	0.031	0.029

Further, the samples were subjected to quenching for release in solution at 950 °C with air cooling, followed by primary aging at 700 °C and tempering at 450 °C (**Figure 1**).

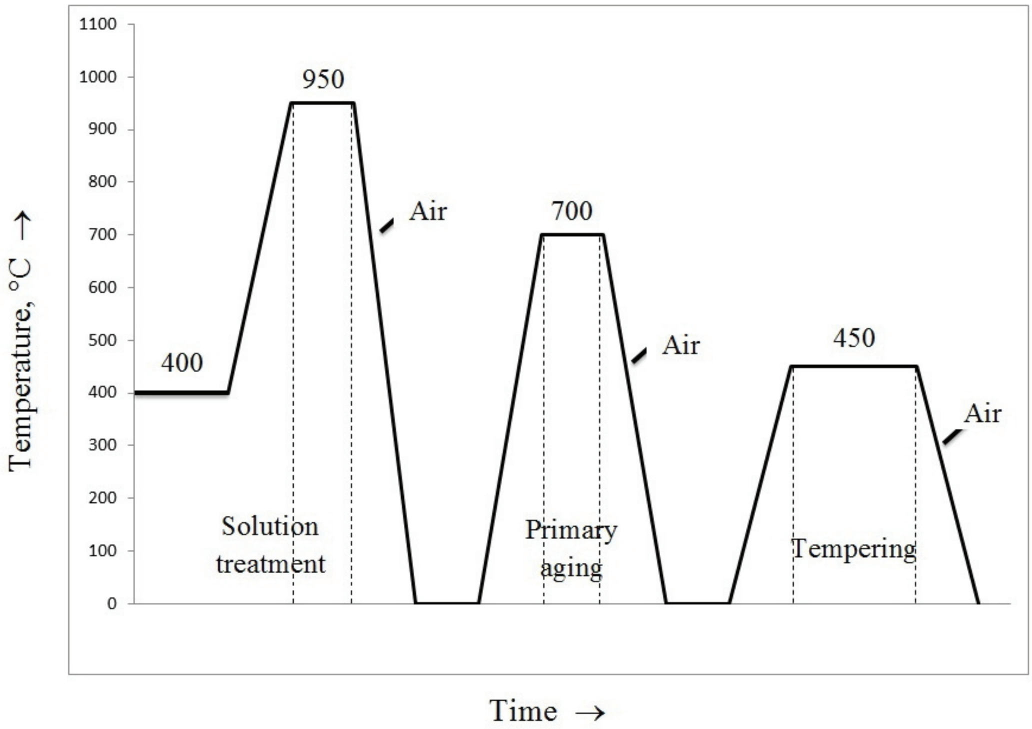


Figure 1 The cycle of quenching heat treatment for release in solution followed by primary aging and tempering

From the material thus treated, samples of cavitation were executed [4,6], which were tested on a vibratory facility with piezoelectric crystals, in conformity with the prescription given by the ASTM G32-2010 Standard [1, 5, 7].

The functional parameters of the apparatus are: electric power developed by the generator: 500 W, vibrations frequency: 20000 ± 200 Hz, vibration amplitude: 50 μm, sample diameter: 15.8 mm, supply voltage: 220 V / 50 Hz, working fluid temperature: 22 ± 1 °C.

According to the customary law of the Cavitation Laboratory of Politehnica University of Timișoara [1, 4, 6], the total testing duration of each sample was 165 minutes divided into periods of 5, 10 and 15 minutes. At the start and at the end of each testing period, the samples were washed under jets of water (from the network), distilled water, alcohol, acetone, dried under hot air and weighed using an analytical balance with an accuracy of 0.01 mg. The eroded surfaces by cavitation in those 165 minutes of attack were subjected to microfractographic investigations at the scanning electron microscope and to roughness measurements. Also, photographs were conducted during the cavitation tests in order to observe the evolution in time of the cavitational erosion, and through metallographic examinations on the sections of the cavitated samples, the degradation mode of structural constituents was highlighted.

3. RESULTS, DISCUSSIONS

Based on the obtained experimental data, curves were plotted showing the variation of the cumulative mass losses (**Figure 2**) and their speed (**Figure 3**) with the attack time by cavitation. For a comparative analysis, the heat treated by quenching for solution treatment at 1050 °C / air, standard OH12NDL steel (samples noted with 1) was considered, which is used at the execution of Kaplan turbine blades from the Hydroelectric Power Plant "Porțile de Fier" România and the steel proposed as a substitute, solution treated at 950 °C / air (samples noted with 2), as the same steel, subjected to primary aging (700 °C / air) and secondary aging (450 °C / air), (samples marked with 3).

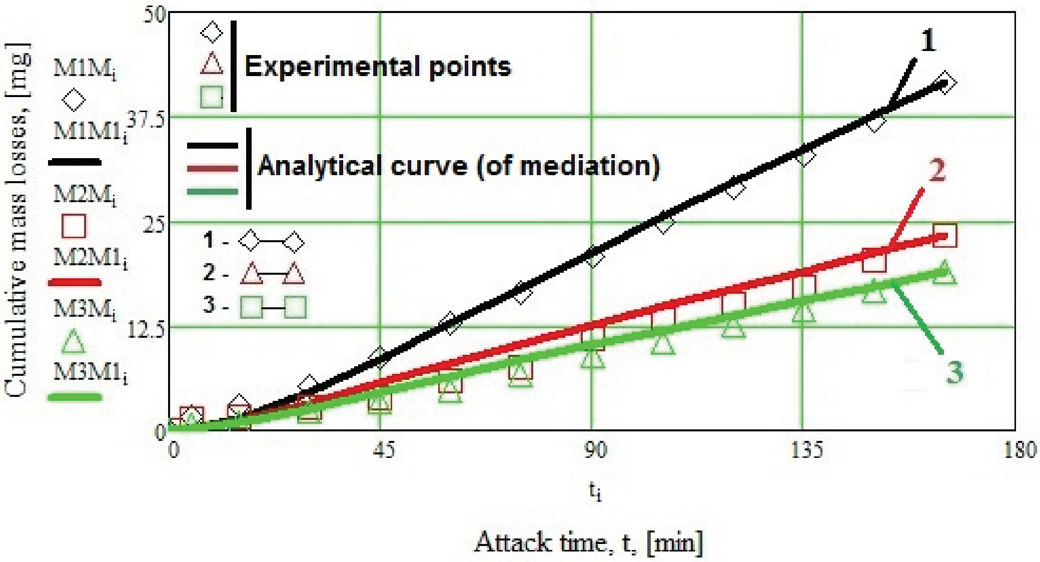


Figure 2 Evolution of cumulative mass losses with the duration of cavitational attack
1 - Standard OH12NDL steel
2 - Quenched 17-4 PH steel at 950 °C / air
3 - Quenched 17-4 PH steel at 950 °C / air + Primary aging at 700 °C / air + Tempering at 450 °C / air

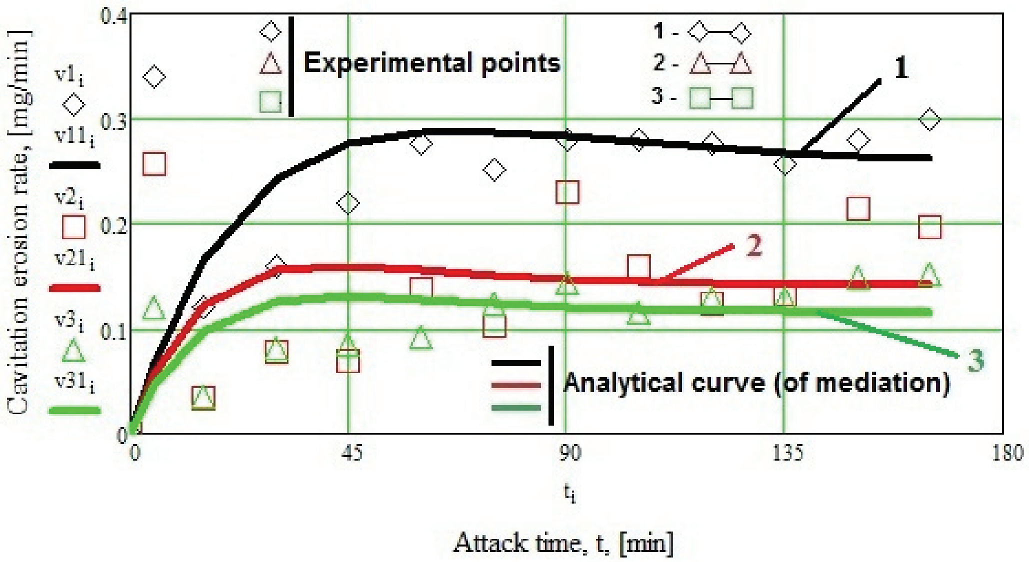


Figure 3 Evolution of cavitation erosion rate with the duration of cavitational attack
1 - Standard OH12NDL steel
2 - Quenched 17-4 PH steel at 950 °C / air
3 - Quenched 17-4 PH steel at 950 °C / air + Primary aging at 700 °C / air + Tempering at 450 °C / air

Both specific erosion curves (**Figure 2** and **Figure 3**) certify that the considered 17-4 PH steel has a better behavior to cavitation then the standard steel. Thereby, the cumulative mass losses (**Figure 2**) are lower by approx. 41 % (structural state of solution treatment at 950 °C - curve 2) and by approx. 57 % (primary and secondary aging state - curve 3). Similarly, the rate of these losses (**Figure 3**) is reduced by approx. 46 % (curve 2) and by 58 % compared to the standard steel (curve 1).

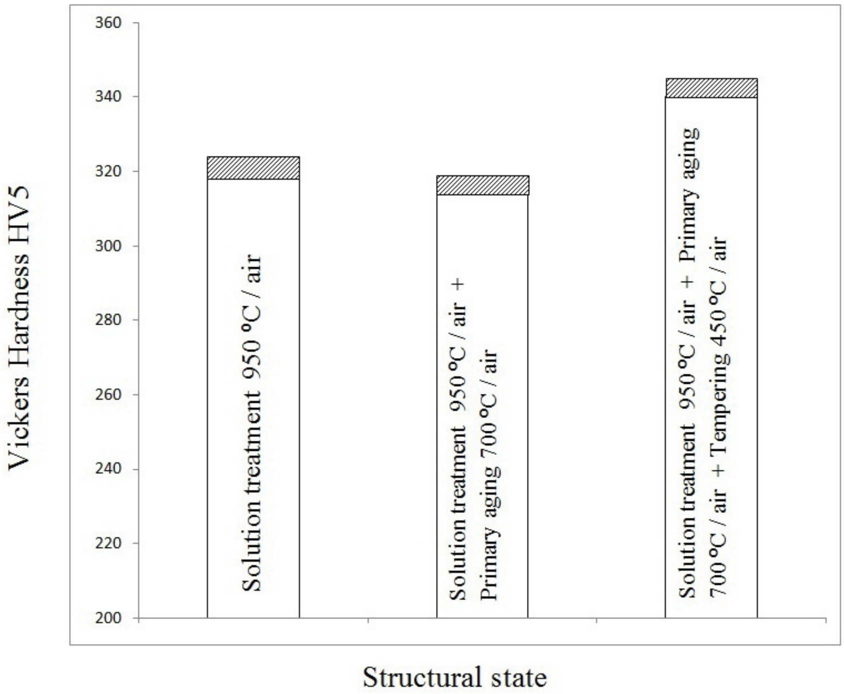
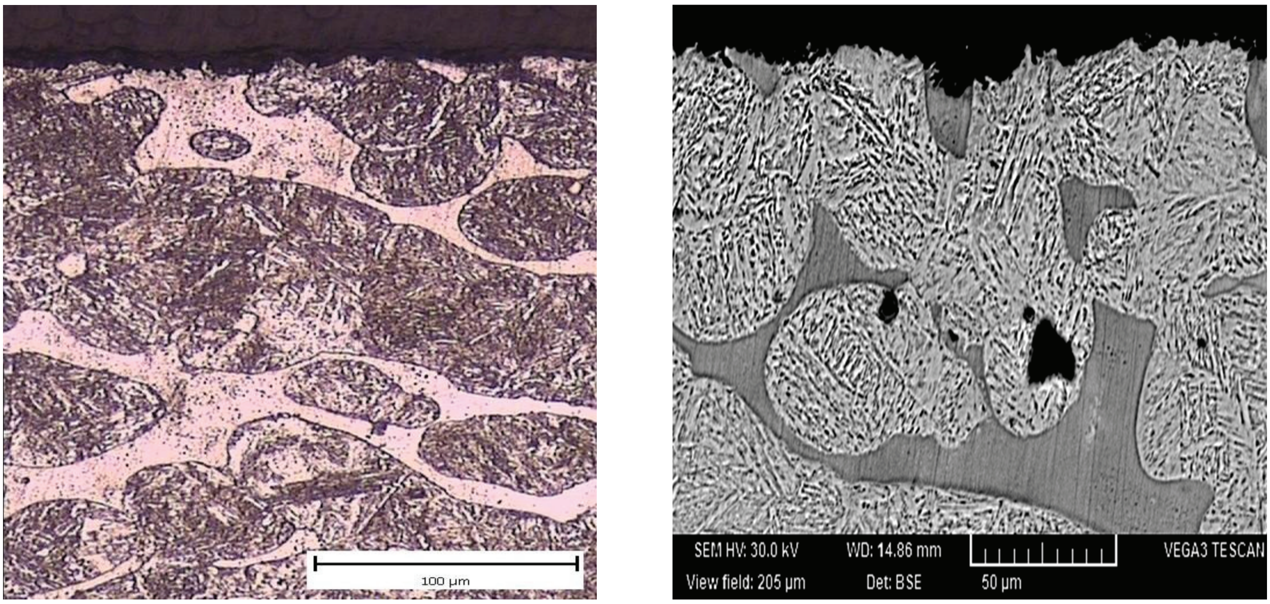


Figure 4 Histogram hardness values of the cast steel samples which were austenitized at 950 °C, primary and secondary aging



a) b)

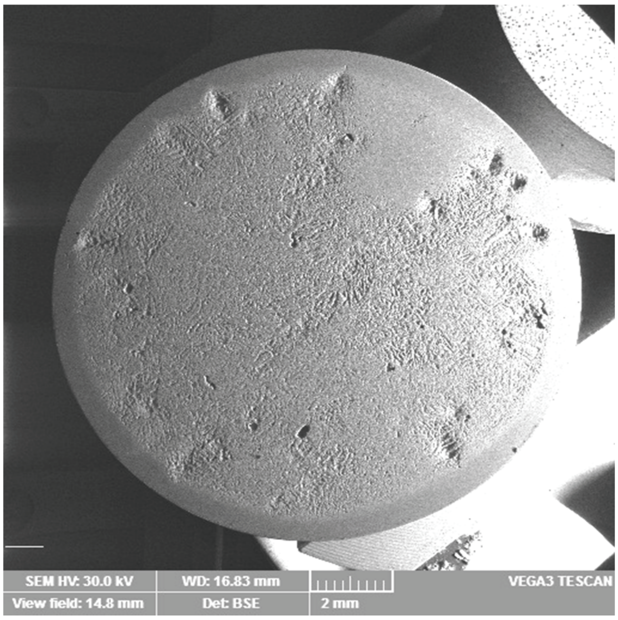
Figure 5 Typical microstructure of the casted steel, after quenching for release in solution at 950 °C, followed by primary and secondary aging, tested at cavitation for 165 minutes: a - MO x 200; b - SEM x 700

In order to substantiate the behaviour of this steel, hardness testing and metallographic investigations were performed. In **Figure 4** the hardness results are centralized for 3 distinct structural states and in **Figure 5a, b** the microstructure of longitudinal sections through the 165 minutes tested samples is exemplified.

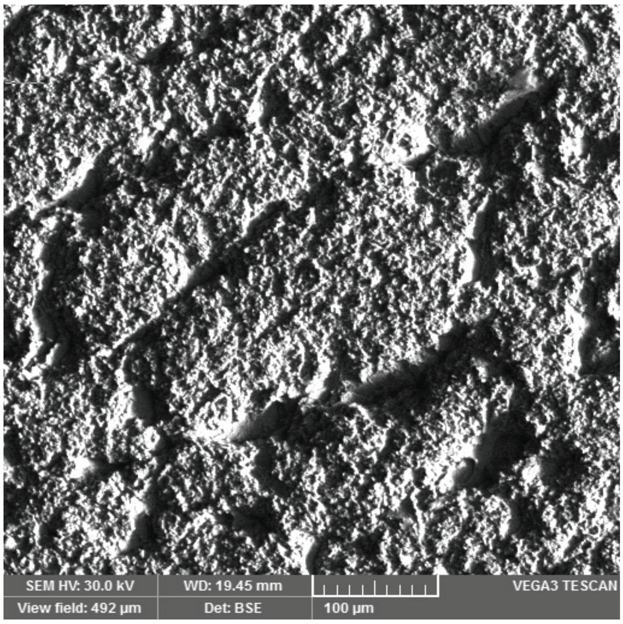
The main observations drawn from these figures can be summarized as:

- the use of a quenching temperature for release in solution at the lower end of the recommended range leads to the raising of Ms critical point temperature; and as a result, the transformation of a significant proportion of metastable austenite in martensite is produced, accompanied by an important increase of the hardness (315 - 325 HV5);
- the primary aging at 700 °C heat treatment does not cause significant changes in hardness (312 - 316 HV5) because in the steel having a reduced carbon content, the proportion of carbide precipitates is limited and the alloying degree of solid solution remains practically unchanged;
- appearance of a secondary hardening at the tempering temperature of 450 °C (338 - 344 HV5), which can be attributed both to the transformation of a major part of austenite into martensite, and to the precipitation of secondary phases considering the presence of the alloying elements (Cr, Mo, Al);
- the initiation of degradation phenomenon of the surface by cavitation occurs mainly through the islands of ferrite δ and on the limits of separation of the grains.

The topography of the affected surfaces (**Figure 6a, b**) show, that the micro-crater depths do not exceed 10 μm and are caused by the preferential cavities of δ - ferrite.



a)



b)

Figure 6 Topography of the casted steel affected surfaces, after quenching for release in solution at 950 °C, followed by primary and secondary aging, tested at cavitation for 165 minutes: a) MO x 10; b) SEM x 300

4. CONCLUSIONS

The solution treatment at 950 °C with air cooling followed by a primary aging at 700 °C and a secondary aging at 450 °C causes at the considerate 17-4 PH steel, a reduction of 57 % of cumulative mass losses and 58 % of its rate, compared with the standard OH12NDL steel.

The improvement of the resistance to cavitation is justified both by secondary hardening reactions triggered after the martensitic transformation, and by precipitation of secondary phases.

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