RESEARCHES UPON CAVITATION EROSION RESISTANCE OF THE AUSTENITIC STAINLESS STEEL GX5CRNI 19-10 HEAT TREATED

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The paper presents the experimental results obtained by testing to cavitation erosion the austenitic stainless steel GX5CrNi19-10 in conformity with SR EN 10283/99 [7] after solution treatment followed by nitration. The test facility used is of magnetostrictive type with nickel tube. The tests have been carried out in Timisoara Hydraulic Machinery Laboratory. The results have been compared with those of the steel 40Cr10 with good but not excellent cavitation erosions and with the steels used for hydraulic turbines T07CuMoMnNiCr165-Nb and T09CuMoMnNiCr185-Ti. For comparisons have been used the characteristic cavitation erosion curves [2, 4] and it resulted that GX5CrNi19-10 has excellent cavitation erosion qualities.

1. INTRODUCTION

Among the negative effects of cavitation, one of greatest importance is the erosion of the solid boundaries guiding the flow [4]. Working out hydraulic machinery with total exclusion of cavitation is not possible for economic reasons. Commonly, the running of hydraulic machinery take place with “industrial allowed cavitation” for which the power characteristics are not at all affected but cavitation erosion is present, in the limits of prescribed material losses of [4].

Anyhow, for the contemporary technique there are not materials that can resist to an intense cavitation action. Instead, for industrial allowed cavitation, the appropriate selection of materials can lead to increased intervals between consecutive repair works and that is highly recommendable from the economic point of view.

In the present work it will be analyzed the cavitation erosion resistance of the austenitic stainless steel GX5CrNi19-10 subjected to solution heat treatment and nitration. The analysis and comparisons will be made using the characteristic values and curves obtained in a vibratory test facility with nickel tube [4].

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2. TESTED MATERIAL

2.1. MECHANICAL AND CHEMICAL PROPERTIES

The tested material is the austenitic stainless steel GX5CrNi19-10, after solution treatment followed by nitration. Besides cavitation erosion tests, there have been made also tests to obtain the chemical composition, the mechanical properties at environmental temperature and metallographic analyses. For tests, 15 mm diameter probes were taken out from the material. The results are presented in table 1.

Table 1

Chemical composition and mechanical characteristics

Steel mark	Status	Chemical composition [%]								Mechanical characteristics at 20ºC				
		C	Si	Mn	P	S	Cr	Ni	Mo	$R_{p0,2}$ MPa	R_m MPa	A5% min	KV J	HB
GX5CrNi 19-10 [1.4308]	ST: 1050 ^{0}C30min. /water	0.048	0.43	1.49	0.028	0.026	19.1	10	0.3	175	440	35	60	230

From these tests it results that the specimens are manufactured from the steel GX5CrNi19-10. In agreement with the standard SR EN10283/99 [7], at first, the specimens were subjected to water solution treatment and afterwards the mechanical characteristics presented in Table 1 were determined.

2.2. METALLOGRAPHIC EXAMINATION

There have been performed macro and micro structural analyses on the specimens, before and after the cavitation erosion tests. The metallographic preparation was carried out according to *General Metallographic Standard* (STAS 4203-94) [8]; *Taking over and Preparation of Metallographic Specimens* and SR EN 5000-97 [7] with regard to *Metallographic Structures and Constituents of Ferrous Products*.

In order to determine the micrographic magnitude of the ferritic, austenitic or Martensitic grain the standard *Metallographic Determinations* SR ISO 643-93 [10] was respected, using the reactive presented in Table 2.

Table 2

Reactive for stainless steels (CR 1236 [11])

Symbol	**Name**	**Composition**	**Surface Preparing**	**Precaution**
B8	Solution of Chlorine hydride and Nitric Acid	39 ml water 59 ml chl. hydr. 9 ml nitric acid Availability: without limits	Diamond paste 3μm or finely Attack Temperature: Ambient temperature Time of attack: From seconds to minutes	Precaution in using acids

The microstructure of the steel GX5CrNi19-10 obtained with an optic microscope provided with a digital camera is presented in Fig. 1.

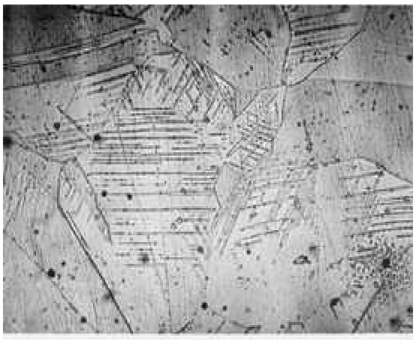


Fig. 1 – Steel GX5CrNi19-10; after solution treatment: 1050ºC/30 min/ water; OM 500×.

It can be clearly seen that the investigated steel has austenitic structure with macles in some grains, the granulation is G = 8, in agreement with the ASTM standard [12].

2.3. HEAT TREATING

- *Solution treatment* (1 050 ^{o}C degrees/30 min/water cooling) and the mechanical characteristics were determined at ambient temperature. Also the metallographic analysis established that after this treatment the steel has austenitic structure with macles in some grains and a granulation G = 8 (Fig. 1), according with ASTM [12].
- *Gas nitrating* as in the complex cyclograma (Fig. 2) with the nitrating temperatures: step I-500 ^{o}C degrees/25 h and step II-520 ^{o}C degrees/28 h nitrating atmosphere and cooling up to 170 ^{o}C degrees and continued in air.

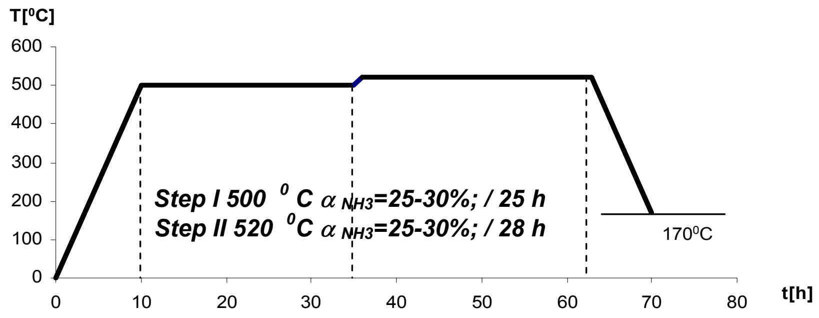


Fig. 2 – Nitration cyclogram.

2.4. EXPERIMENTAL RESEARCHES UPON THE CAVITATION EROSION OF THE SPECIMENS MANUFACTURED FROM GX5CRNI19-10

In conformity with the ASTM standard [12] the tests were carried out on three probes, in distilled water at the temperature $T = 20 \pm 1$ ºC.

The cavitation attack was realized at Timisoara Hydraulic Machinery Laboratory in a vibratory magnetostrictive test facility with nickel tube. The facility is characterized by the following parameters:

- vibration amplitude: $A = 94$ μm;
- frequency: $f = 7{,}000 \pm 3$ Hz;
- pressure at the liquid surface: $p = p_{at}$;
- power: $P = 500$ W;
- specimen diameter: $d = 14$ mm;
- specimen immersion: $h = 3$ mm.

The total duration of the cavitation attack of 165 minutes was divided in 12 periods, as follows: one of 5 minutes, one of 10 minutes and 10 of 15 minutes. At the beginning and at the end of each period the specimens have been washed successively in current water, distilled water, alcohol, acetone, after that desiccated in a hot air current and finally weighed in an analytical balance with six characteristic figures.

3. EXPERIMENTAL RESULTS

The cavitation erosion velocities v_s have been obtained, for each attack period Δt, from the mass losses Δm_a using the relation:

$$v = \frac{\Delta m_a}{\Delta t} \; [\mathrm{g/min}].$$

The measured and computed data are presented in Table 3 "Testing Bulletin" and subsequently the following cavitation erosion characteristic curves have been obtained:

- Variation in time (Fig. 3) of the cavitation eroded mass $m_a(t)$;
- Variation in time (Fig. 4) of the cavitation erosion velocity $v(t)$;
- Observation: the value m_a in the "Test Bulletin" is obtained averaging the mass losses of the three tested specimens.

Table 3

Testing bulletin

Time [min]	**Eroded mass $m_a \times 10^3$ [g]**	**Erosion velocity $v_s \times 10^5$ [g/min]**
0	0	0
5	0.065	1.3
15	0.29	2.31
30	1.11	5.5
45	2.18	7.18
60	3.41	8.25
75	4.73	8.80
90	6.09	9.11
105	7.47	9.20
120	8.85	9.20
135	10.23	9.20
150	11.61	9.20
165	12.99	9.20

Magnetostrictive facility with nickel tube
Material: stainless steel GX5CrNi19-10
Test liquid: distilled water
Control amplitude: 94 μm
Mean frequency: 7000 ± 3% Hz
Temperature of the working liquid: 20 ± 1 ºC

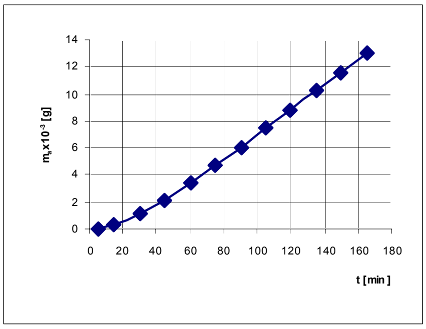


Fig. 3 – Eroded mass.

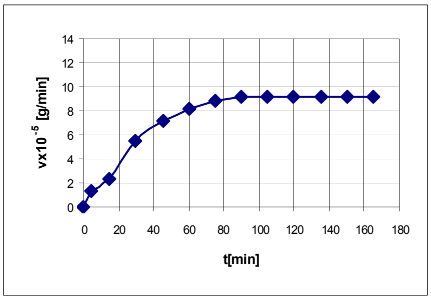
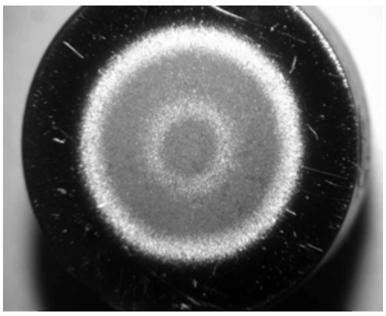


Fig. 4 – Erosion velocity.

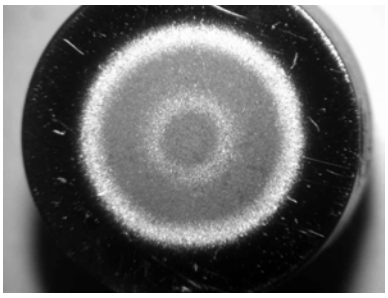
4. THE METALOGRAPHIC ANALISIS OF THE CAVITATION ERODED SPECIMENS

4.1. THE MACROSCOPIC ANALYSIS OF THE SPECIMENS

The macroscopic analysis of the tested specimens, at various test durations is presented in Fig. 5.



a)



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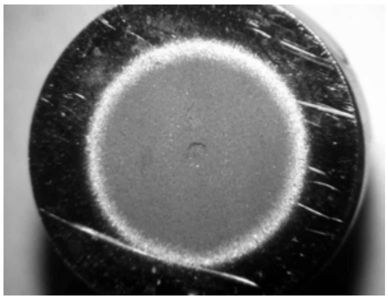
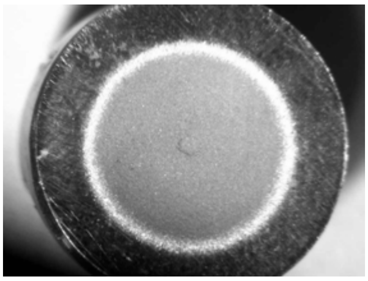


c)



d)

e)

Fig. 5 – The macroscopic structure of the steel GX5CrNi19-10 for different cavitation test duration: a) 75 min, OM 10×; b) 105 min, OM 10×; c) 165 min, OM 10×; d) 165 min, OM 10×; e) 165 min, OM 20×.

Through macroscopic and microscopic analyses it was put into evidence the manner in which the cavitation erosion take place, inclusively the granulation and structural modifications of the layers subjected by cavitation (Figs. 5, 6, 7, 8, 9).

The macroscopic analyses were realized with a stereomicroscope, at different aggrandizements and the following cavitation eroded area were observed:

- a central zone is heavily eroded and presents crakes and microcrackes;
- a zone adjacent to the central one has only shallow erosions;
- a third zone is also heavily eroded and presents microcrackes;
- a fourth zone has only few erosions.

In some area there has been seen detachments of grains and the occurrence of some porous zones.

4.2. THE STRUCTURE OF THE CAVITATION EROSION TESTED SPECIMENS MANUFACTURED FROM THE AUSTENITIC STEEL HEAT TREATED

The samples from the stainless steel GX4CrNi13-4, after the cavitation tests were sectioned on the generatrix, prepared and analyzed metallographic. The metallographic attack was made with the reactive CR 12361 [11]. The metallographic examination was made with an optical microscope having a photo camera.

The structure of the specimens is presented in the, Figs. 6, 7, 8, 9.

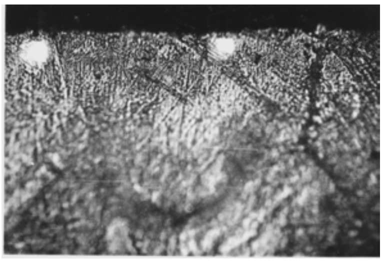


Fig. 6 – Area affected by cavitations with a micro cracks, detachments and grain expulsions – OM 500×.

Fig. 7 – Area affected by cavitations with a micro cracks, detachments and grain expulsions – OM 500×.

Fig. 8 – Area affected by cavitations with a grain finish and complex precipitation – OM 500×.

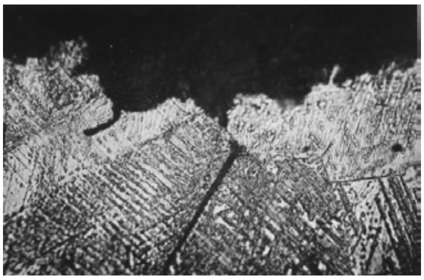


Fig. 9 – Area affected by cavitations with a grain finish and complex precipitation – OM 500×.

Note: STATE – solution treatment and nitration (Figs. 6, 7, 8, 9), OM – optical microscop.

The metallographic analysis of the samples subjected to cavitation erosion tests put into evidence the following aspects:

- In the area unaffected by cavitations, a homogenous austenitic structure with some macles in some grains, with $G = 8$ (Fig. 1).
- In the areas affected by cavitations appear micro cracks on a intergranular layer, detachments and grain expulsions (Figs. 6, 7).
- In the area affected by cavitations appears a grain finish and complex precipitation off and in the austenitic grains (Figs. 8, 9).
- To the gassed nitrating probes appears an iron nitrating and nitrates of the adding elements with a thickness untill 0.10 mm.
- Between the nitrating layer and the submissive nitrating material appears a transition layer with nitrates and nitrating precipitations in crystalline grains.

The mechanism of cavitational erosion consists in a melted area, the micro cracks, structural modifications with a smaller intensity that in the case of the solution heat treatment.

4.3. MICRO HARDNESS MEASUREMENTS

For the austenitic steel, after the solution tempering, there appears a decrease of the hardening from 200 to 185 HV0.2 in the area affected by the cavitations; this situation is in total conformity with the metallographic investigation [2, 4].

The application of the gas nitrating produce for the Austenitic steel, an increase of the hardening a depths from 0.1mm from 185 to 370 HV0.2. The increase of the hardening is in conformity with the structural state and justifies the growth of resistance at corrosion (Fig. 10a).

In the areas affected by cavitations the micro hardening approaches the one given by the treatment which was applied initial, a normal situation because through cavitations the nitride layer was destroyed (Fig. 10b,c).

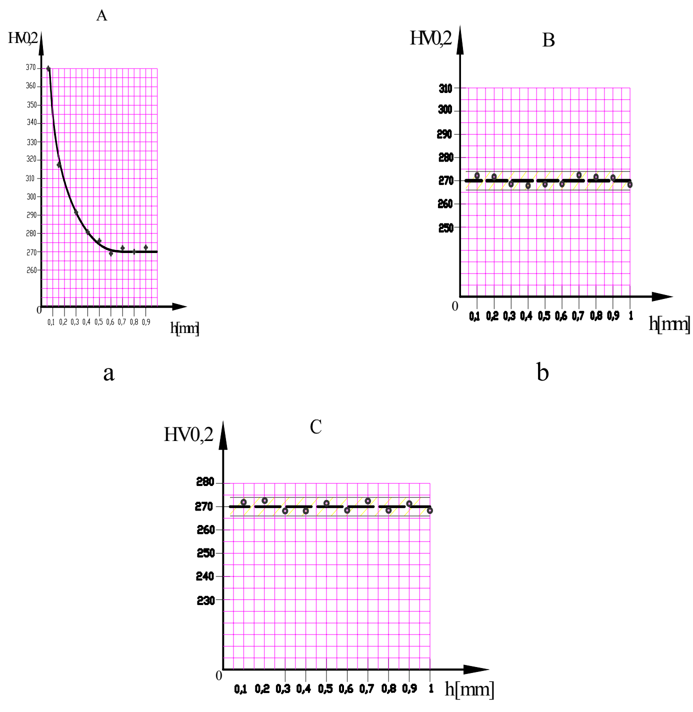


Fig. 10 – The hardness HV 0.2, State: solution treatment and nitration.

5. ANALYSIS OF EXPERIMENTAL RESULTS

From Table 3 and Fig. 3 it results that the total lost mass is very restrained m_a = 12.99 mg after 165 min cavitatonal attack.

The characteristic curve cavitation erosion velocity function of time (Fig. 4) presents a stabilization value $v_s = 9.20\times10^{-5}$ g/min = const. at a very low level.

The velocity in time curve presents a maximum erosion velocity equal with the stationary one $v_{max} = v_s$ and differs from the curves $v(t)$ analyzed in [4] for which in the first 30 minutes it presents a maximum value of the velocity $v = v_{max}$ and after that the curve shows an attenuation, till the stabilization value $v = v_s$ is attained.

In Table 4 there are made comparisons between the eroded masses erosion velocity after 165 minutes of cavitation attack and the steady state erosion velocities for many steels used in the manufacturing of hydraulic machinery [1, 4].

Table 4

Steady state erosion velocity and eroded mass

Steel mark	**Erosion velocity** $v_s\times10^5$ **[g/min]**	**Eroded mass** $m_a\times10^3$ **[g]**
GX5CrNi19-10 -solution treatment	13.50	13.20
GX5CrNi19-10 solution treatment and nitritition	**9.20**	**12.99**
40Cr10	35.00	45.00
GX5CrNiMo13-6-1	22.00	32.00
T07 CuMoNiCr 165-Nb	13.60	14.50
T09 CuMoMnNiCr 185-Ti	15.00	15.00

6. CONCLUSIONS

The cavitation erosion of the specimens takes place slowly, gradually and without important craters.

The austenitic steel GX5CrNi19-10 before heat solution treatment has an austenitic structure with carbides precipitated at grain boundaries:

- after the recommended heat solution treatment, the grain boundaries carbides were dissolved and the homogeneity of austenite is improved;
- nitration produce for the Austenitic steel, an increase of the hardening a depths from 0.1mm from 185 to 370 HV 0.2;
- the increase of the hardening is in conformity with the structural state and justifies the growth of resistance at corrosion;
- gas nitriding gives to steel the biggest resistance at cavitational erosion;
- the experimental study for cavitations on the samples made out of austenitic steel GX5CrNi19-10 have shown that the steel has the bigger resistance for cavitational erosion in all technological variants of thermal treatment applied and it is highly recommended for casting all rotors of hydraulic turbine.

The cavitation erosion resistance of the steel GX5CrNi19-10 after solution treatment and nitriding became better in comparison with other steels used commonly in manufacturing the hydraulic turbines runners.

The tests carried out with the stainless steel GX5CRNI19-10 certify a good behavior at cavitation erosion and it is useful to undertake studies for employing it in hydraulic machinery manufacturing.

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