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EXPERIMENTAL RESEARCHES UPON CAVITATION EROSION RESISTANCE OF THE AUSTENITIC STAINLESS STEEL HEAT TREATING BY SOLUTION TREATMENT AND NITRIDING

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Abstract: *Paper presents the experimental results obtained by testing to cavitation erosion the austenitic stainless steel GX5CrNi19-10 in conformity with SR EN 10283/99 [1] 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.*

Keywords*: cavitation erosion, austenitic stainless steel, heat treatment, nitriding.*

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].

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

Steal	Status	Chemical composition [%]								Mechanical characteristics at 20ºC				
		C	Si	Mn	P	S	Cr	Ni	Mo	$Rp_{0,2}$ MPa	Rm MPa	A5% min	KV J	HB
GX5CrNi 19-10 1.4308	CS 1050 30min 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, at first, the specimens were subjected to water quenching 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 4203-74) [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 [8])

Symb.	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 Figure 1.

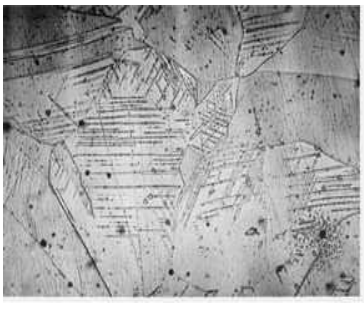


Fig. 1 - Steel GX5CrNi19-10; after solution treatment: 1050ºC/30 min/ water; OM 500x

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 [5], [6] **-** (1050 ^{0}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=6, according with ASTM [12] (fig. 1)

-Gassed nitriding - as in the complex cyclograma (fig. 2) with the nitriding temperatures: step I-500 ^{0}C degrees/25 h and step II-520 ^{0}C degrees/28 h nitriding atmosphere and cooling up to ^{0}170 ^{0}C degrees and continued in air [5], [6].

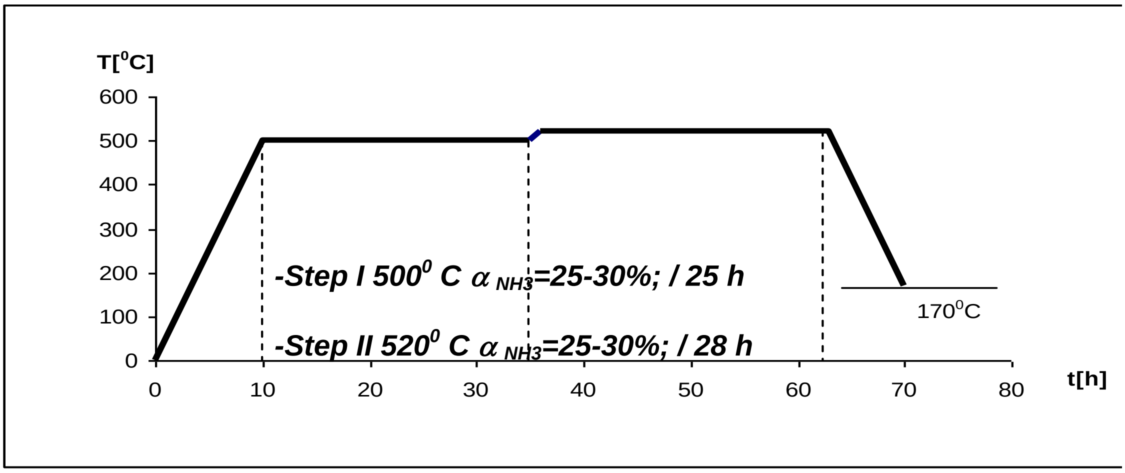


Fig.2 Nitration Cyclogram

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 ± 1ºC.

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 ± 3 Hz;
- pressure at the liquid surface: $p = p_{at}$;
- power: P = 500 W;
- specimen diameter: d=14 mm;
- specimen immersion: h = 3mm.

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:

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

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

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

Table 3

Timp [min]	m_a x 10^3 [g]	v x10^5 [g/min]
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	8,8
90	6,09	9,11
105	7,47	9,2
120	8,85	9,2
135	10,23	9,2
150	11,61	9,2
165	12,99	9,2

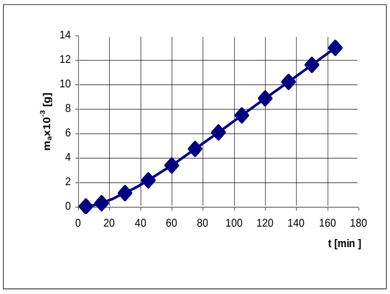


Fig. 3 Eroded Mass

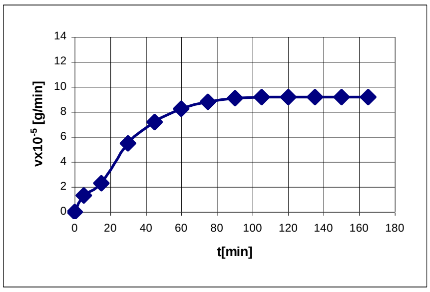
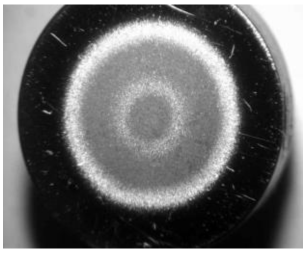


Fig. 4 Erosion Velocity

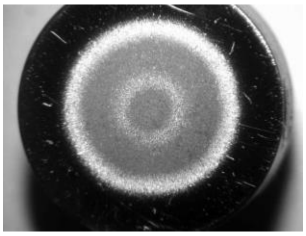
4. The metalographic analisis of the cavitation eroded specimens

4.1 The Macroscopic Analysis Of The Specimens

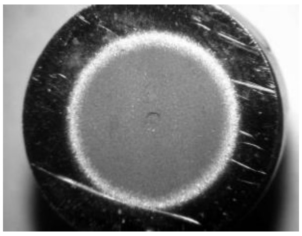
The macroscopic analysis of the tested specimens, at various test durations is presented in Figure 5.



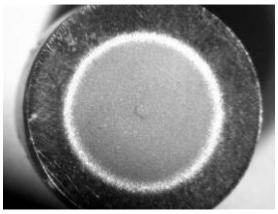
(a)



(b)



(c)



(d)

(e)

(a)75 min OM 10X,
(b) 105min OM 10X,
(c)165min, OM 10X
(d) 165min OM 10X,
(e) 165min, OM 20X

Fig. 5 – The macroscopic structure of the steel GX5CrNi19-10 for different cavitation test duration

Through macroscopic 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 (Fig.5, a, b, c, d, e)

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.

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 x10^{-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 and 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 x10^5 <g/min>	Eroded mass m_a x10^3 <g>
GX5CrNi19-10-solution treatment	13.5	13.2
GX5CrNi19-10 solution treatment and nitritition	**9.20**	**12.99**
40Cr10	35	45
GX5CrNiMo13-6-1	22	32
T07 CuMoNiCr 165-Nb	13.6	14.5
T09 CuMoMnNiCr 185-Ti	15	15

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.
- in the samples under nitration there appears a superficial layer made of nitrides, a transitional layer and then a structure of austenitic structure.
- in the cavitational area there will be modifications of precipitates in the nitrated layer, microcrackes and expulsion of micro grains. It was remarked the finishing of the granulation and the nitrides
- 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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CECETARI EXPERIMENTALE PRIVIND REZISTENTA LA EROZIUNE CAVITATIONALA A OTELULUI AUSTENITIC TRATAT TERMIC PRIN PUNERE IN SOLUTIE SI NITRURARE

Rezumat

Lucrarea prezintă rezultatele cercetărilor experimentale obţinute prin analiza oţelului austenitic GX5CrNi19-10, tratat termic prin călire de punere în soluţie urmată de procedura de nitrurare gazoasă. S-au făcut teste la atacul cavitaţional determinându-se viteza de eroziune şi masa erodată. Am tras concluzii în ceea ce priveşte mecanismele distrugerii cavitaţionale. S-au facut comparaţii cu oţeluri din mărci consacrate în construcţia rotoarelor turbinelor hidraulice concluzionând că oţelul în discuţie se comportă foarte bine la testele de atac cavitaţional.

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