CAVITATION EROSION RESISTANCE OF THE AUSTENITIC STAINLESS STEEL FROM WELDING RECONDITIONED HYDRAULIC TURBINES BLADES ZONES

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Abstract: Samples of the austenitic stainless steel GX5CrNi19-10 have been thermally treated and tested under cavitation erosion. There have been obtained modifications of the cavitational resistance dependent on the thermal treatment by use of structural analyses and micro hardness tests the influence of microstructure on the steel cavitation resistance had been stressed out. The paper presents the researches carried on upon the cavitation erosion of austenitic stainless steel GX5CrNi 19-10 (SR EN 10283/99) [8] after solution treatment used for manufacturing Kaplan and Francis runner blades. The research is focused on the thermal influenced zones subsequently of the welding process performed in the repair work [5]. The thermal treatment of solution treatment followed by welding give a high cavitational erosion resistance to austenitic stainless steel GX4CrNi19-10.

1. INTRODUCTION

The erosion intensity depends on a great variety of factors, such as: structural state, the blade material, the suction height, [1], [2], [3], [4], [5]. Papers [3], [4], [5], [6], [7] for the stainless steel showed: composition characteristic, variant of thermal treatment (the thermal treatment of solution treatment followed by welding), the eroded masses and the erosion velocity for each variant of thermal treatment determined by cavitational attack in a vibratory magnetostrictive test facility with nickel tube.

From economical reasons, as a rule, the hydraulic turbines are running with a so called “industrial allowed cavitation”, for which the power characteristics are not affected but the phenomenon is present and causes erosions, in accepted limits of material losses [5]. The repair work of these damages is commonly carried out by welding. A feeble area of the repaired surface is the boundary zone between the genuine material and that added by welding. This is the reason why in the present work that area is our main concern [5].

2. MATERIALS USED FOR CASTING KAPLAN AND FRANCIS TURBINE BLADES

The materials used for manufacturing turbine elements must fulfill simultaneous numerous structural, chemical, mechanical and physical conditions [2], [3], [5], [6], [7]. From the literature, we extracted the necessary characteristics for a material with good resistance to cavitation; these are presented in [5]. A compromise must be found between the hardness and the tenacity. This problem can be solved through structural modifications achieved by various heat treatments In this case heat solution treatment must assure an increase of the resistance to corrosion, erosion and fatigue. In our country, for manufacturing Kaplan turbine blades or Francis impellers, there are used the materials presented in [5]. The austenitic and martensitic stainless steels commonly used for manufacturing hydraulic machinery elements, having good cavitation erosion resistance are presented in SR EN 10283/99 [5], [8].

3. TESTED MATERIAL

3.1 CHEMICAL COMPOSITION AND MECHANICAL CHARACTERISTICS

The specimens tested to cavitation erosion are manufactured from the Austenitic stainless steel GX5CrNi19-10 (SR EN 10283/99) [8] after heat solution treatment. The chemical composition and the mechanical characteristics determined on prismatic samples are presented in table no. 1. From these tests it results that the specimens are manufactured from the steel GX5CrNi19-10. In agreement with the standard SR EN10283/99 [8], at first, the specimens were subjected to solution treatment.

Table no. 1

Steel mark Solution Treatment 1050 °C/ 30 min water	Chemical composition %								Mechanical characteristics at 20ºC				
	C	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Mo**	Yield strength Rp0,2 [MPa]	Fracture Strength Rm [MPa]	Linear Extension A5 [%]	Resiliency KV [J]	Brinell Hardness HB [-]
GX4CrNi 13-4 1.4317	0.048	0.43	1.49	0.028	0.26	19.1	10	0.3	175	440	35	60	230

3.2 METALLOGRAPHIC EXAMINATION

There have been performed macro and micro structural analyses on the specimens, before and after the cavitation erosion tests. The microstructure of the steel GX5CrNi19-10 obtained with an optic microscope provided with a digital camera is presented in figure no. 1. 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 [9].

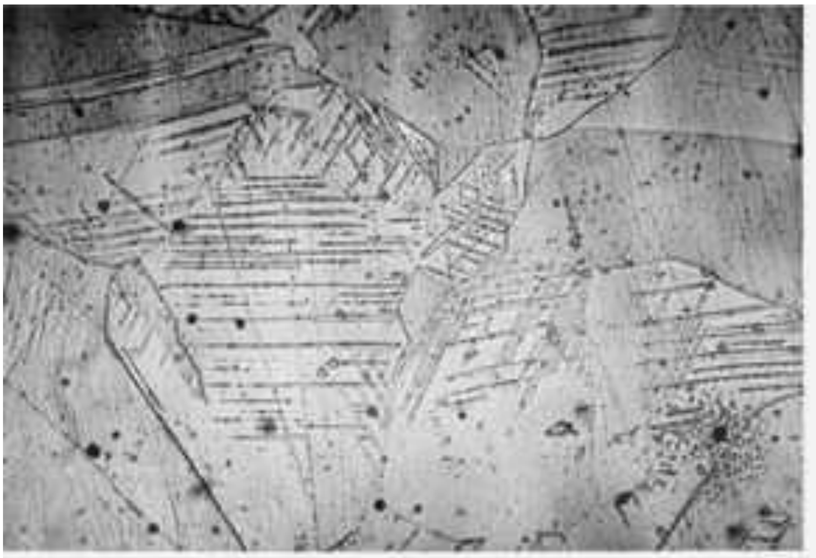


Fig. 1 - The microstructure of the steel GX5CrNi19-10 after
Heat Solution Treatment: 1050ºC/30 minutes/ water;
OM 500X - Optical microscop with 500X increase factor

4. RESEARCHES UPON THE CAVITATION EROSION OF THE THERMAL INFLUENCED ZONE DURING THE WELDING PROCESS

4.1 MATERIALS AND SAMPLES

Between two successive repair works, a great importance for the turbine running has the behavior of the thermal influenced zone. To obtain information that is more useful, the present research is concerned with this influenced zone, so the samples were manufactured from the thermal influenced area.

The cylindrical samples undergo welding loads, simulating the repairs of the zones deteriorated through cavitation of the hydraulic runner blade. Corresponding to the [5] there would be put down Austenitic stainless steel, on the cilindric samples 20 mm, three welded layers. From the cylindrical bar loaded with those three welded layers there were manufactured a cylindrical bar ø 20 x 48 mm. The thermal influenced zones was rendered evident through an attack with the reactive NITAL. The semi-finished piece was cut from the boundary "base metal-welded metal" and finally it was obtained the sample with 14 mm diameter.

4.2 THE LOADING THROUGH WELDING

The welding procedure is electrical with covered electrodes. The temperature of preheating is T_1=120°C.The temperature between the layers was T_2=150°C. The welding regime and the electrodes dimension are presented in table no. 2.

Table no. 2

Row	The dimension of the added metal [mm]	Current intensity [A]	Voltage [V]	Type of current	Welding velocity [cm/min]	The thermal energy introduced [J/cm^2]	Layer
1, 2, 3	Φ3.2	90-100	23-25	CC^+	10-12	10,350-15,000	damping

For the damping layers are used the electrodes mark: Selectarc 18.8 Mn Standard: EN 1600: E 18.8 Mn R73.

Chemical composition and mechanical characteristics of electrodes of the damping layers are presented in table no. 3.

Table no. 3

C	Mn	Si	Cr	Ni	Rm [Mpa]	R $p_{0.2}$ [Mpa]	A5 [%]	HB	KV[J]
0,10	5.0	0.8	18.0	8.5	600-730	min 400	min 30	180	min 70 at +20^0 C

5. RESEARCHES UPON THE CAVITATION EROSION OF THE SPECIMENS MANUFACTURED FROM GX5CRNI 19-10

In conformity with the ASTM standards [9] the tests were carried out on three probes, in distilled water at the temperature T = 20.00 ± 1.00 ºC. The cavitation attack was realized at Timisoara Hydraulic Machinery Laboratory in a vibratory magnetostrictive test facility with nickel tube. The results are presented as mean value of three specimens. The facility is characterized by the following parameters [3], [4], [5]:

- vibration amplitude: A = 94.00 µm;
- frequency: f = 7,000 ± 3.00 Hz;
- pressure at the liquid surface: p = pat;
- power: P = 500.00 W;
- specimen diameter: d=14.00 mm;
- specimen immersion: h = 3.00 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 decimals.

5.1 EXPERIMENTAL RESULTS

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

$$V = \frac{\Delta m_a}{\Delta t} \quad [g/min] \qquad [1]$$

The following cavitation erosion characteristic curves have been obtained experimentally:

- variation in time of the cavitation eroded mass **m_a(t),** figure no. 2;
- variation in time of the cavitation erosion velocity **v(t),** figure no. 3.

Taking into account the data from figure no. 2, 3, it results that the Austenitic steel GX5CrNi19-10, subjected to the solution treatment, attains, after 80 minutes, the characteristic cavitation erosion figures: $\mathbf{v_s} = 5.00 \times 10^{-5}$ [g/min] and $m_a = 6.70 \times 10^{-3}$ [g]; the total duration of the test was, of course, 165 minutes.

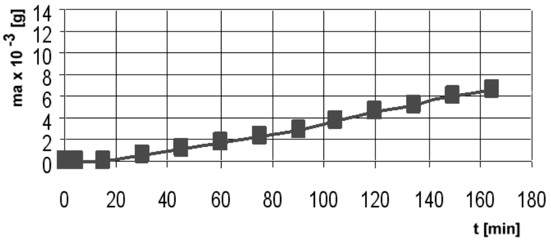


Figure no. 2 Eroded mass

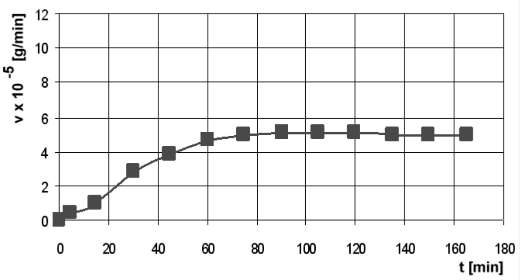


Figure no. 3 Erosion velocity

6. THE METALOGRAPHIC ANALISIS OF THE CAVITATION ERODED SPECIMENS

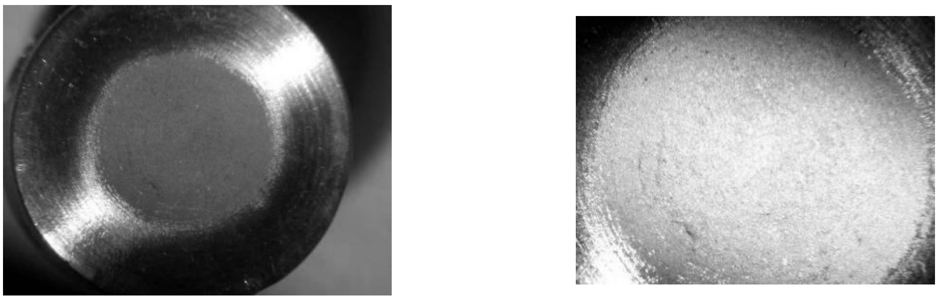
6.1 THE MACROSCOPIC ANALYSIS OF THE SPECIMENS

The cavitation-tested specimens were analyzed at various aggrandizements using a stereomicroscope. 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 (figures no. 4 a and b).

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 microcrakes (figure no. 4b);
- a zone adjacent to the central one has only shallow erosions (figure no. 4a);
- a third zone is also heavily eroded and presents microcrakes (figure no. 4b);
- a fourth zone has only few erosions (figure no. 4a).

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



a) After the cavitation erosion tests
Optical microscop with 10X increase factor

b) After heat solution treatment and welding
Optical microscop with 20X increase factor

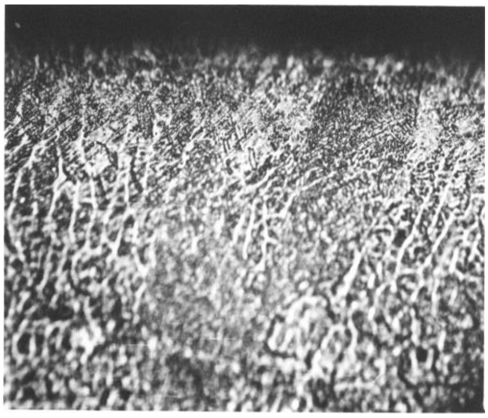
Figure no. 4 The macroscopic aspect of the steel GX5CrNi19-10

6.2 THE STRUCTURE OF THE CAVITATION EROSION TESTED SPECIMENS MANUFACTURED FROM THE STEEL GX5CRNI 19-10 AND HEAT TREATED THROUGH SOLUTION TREATMENT AND WELDING

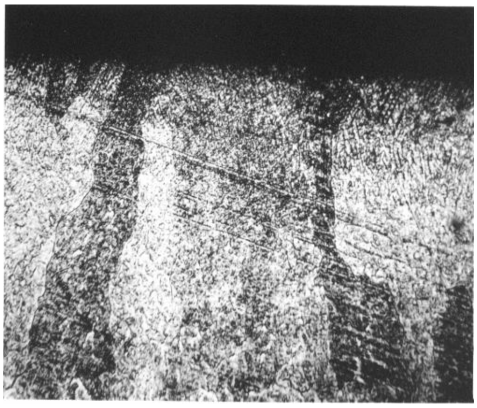
The samples from the stainless steel GX5CrNi19-10, after the cavitation tests were sectioned on the generatrix, prepared and analyzed metallographical. The metallographic attack was made with the reactive CR 12361. The metallographic examination was made with an optical microscope having a photo camera. The structure of the specimens is presented in the figure no. 5, 6, 7, 8.

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

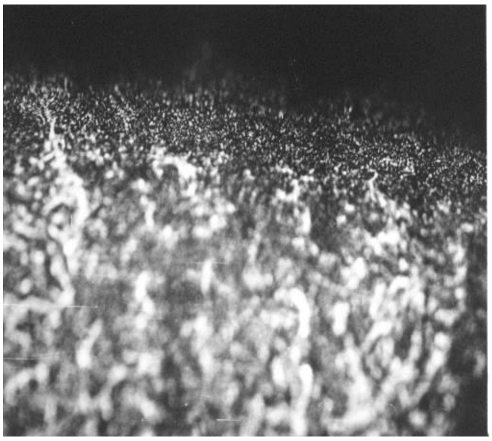
- the development dendritic of the crystalline grains perpendicular at frontal welder (figure no. 5, 6);
- the fines structure in the thermal influenced zone with the numerous fines precipitate intergranular complex carbides (figure no. 6);
- it appears also a finishing of the granulation in the thermal influenced zone, (figure no. 7);
- taking off and the expulsion of some material particles, (figure no. 8);
- breaking up of the crystalline grains, formation the micro fissures and the intensification of the separations of complex carbides at the boundaries of the grains, (figure no. 7, 8).



Optical microscop with 100X increase factor
Figure no. 5



Optical microscop with 500X increase factor
Figure no. 6



Optical microscop with 500X increase factor
Figure no. 7

Optical microscop with 500X increase factor
Figure no. 8

6.3 MICRO HARDNESS MEASUREMENTS

In the zone unaffected by cavitation(figure no. 9), at depths until 0.8 mm, the measured durities are the same as for the steel under heat treatment at heat solution treatment, HV 0,2 - 180.

In the passing zones from the unaffected material to the cavitation eroded material (figure no. 10), at depths until 0,4 mm, it can be seen a malleable deformation of the steel until the HV 0,2 - 240 durities.

For depths of 0,4 mm until 0,9 mm, the measured durities are HV 0,2 - 190, as for the steel under heat treatment of heat solution treatment.

In the most exposed area to the cavitation erosion (figure no. 11), it can be seen a strong malleable deformation of the steel, the hardness reaching in the superficial stratum - HV 0,2 - 330.

The present metallographic researches did not revealed the cause of these durities and it most be imposed a more detailed research through electronic metallographic and irradiations with X ray.

We suppose that, through cavitation erosion, tensed processes were induced in the adjacent strata, justifying the malleable deformation of the material.

At depths over 0.7 mm, the hardness is equivalent with HV 0,2 - 190, as for the material under thermal treatment with heat solution treatment.

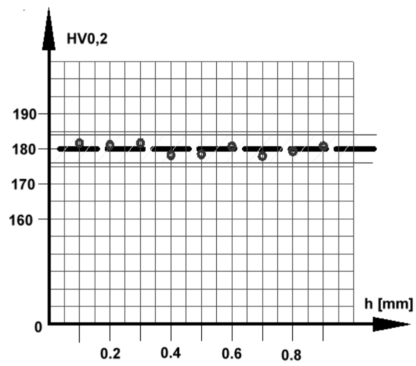


Figure no. 9

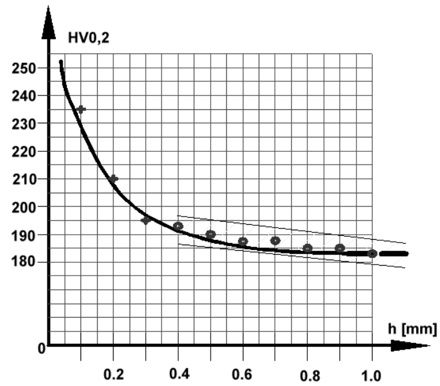


Figure no. 10

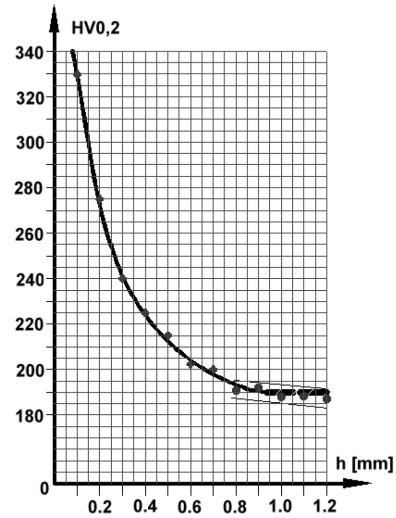


Figure no. 11

The same conclusion is obtained from the comparison of the steady state velocities $\mathbf{v_s}$ or the final eroded masses $\mathbf{m_a}$ of some steels with a good behavior at cavitation [3], [4], [5] (table no. 4):

Table no. 3

Steady state erosion velocity and final eroded masses

Steel mark	Mass eroded m_a x10^3 [g]	Erosion velocity V_s x10^5 [g/min]
GX4CrNi13-4	17.63	12.50
40Cr10	51.00	35.00
GX5 CrNiMo13-6-1	33.24	22.00
T07CuMoMnNiCr165-Nb	20.67	13.6 0
T09CuMoMnNiCr185-Ti	22.77	15.00
GX5CrNi19-10/solution treatment	13.50	13.20
GX5CrNi19-10/solution treatment/welding	**6.70**	**5.00**

7. CONCLUSIONS

The austenitic steel GX5CrNi19-10 before heat treatment has an austenitic structure with carbides precipitated at grain boundaries. After the recommended heat treatment, the grain boundaries carbides were dissolved and the homogeneity of austenite is improved. The cavitation erosion of the specimens takes place slowly, gradually and without important craters. The restoration of the eroded zones through the cavitation phenomenon is realized through welding with corresponding materials and specific procedures.

It was simulated the repair of the blades manufactured from stainless steel GX5CrNi19-10, using for the damping layers the electrodes Selectarc 18.8 Mn.

The welding was made with direct current; the used energies were in the range of 10,350-16,900 J/cm2. The probes tested at cavitation were taken from the thermal influenced zone of the welding. The obtained steady-state velocity was v_s=5.00 x 10^{-5} [g/min] and the eroded mass was m_a=6.70 x 10^{-3} [g], fact that confirms a high cavitation resistance of the thermal influenced zone.

The steel GX5CrNi19-10 after solution treatment has m_a=13.50 x10^{-3} [g] and v_s=13.20 x 10^{-5} [g/min].

The damages through cavitation were achieved through the attack at the boundaries of the crystalline grains, the formation of micro-fissures and by breaking into pieces of some grains.

The material in the cavitation zone presents also structural modifications on small depths. It appears also a finishing of the granulation and an agglomeration of complex carbides at the limit of the grains.

The research made through the simulation of the welding of the damaged cavitation zones show that the blade can be rebuilt at the normal dimensions and a growing of resistance at the cavitation attack is obtained.

Through the structure fines, the homogeneity of the granulation and the uniform dispersion of carbides, the steel that we talk about presents in the thermal influenced zone a good cavitation resistance.

It is recommended to put into industrial practice this repair work procedure, for the blades made from the stainless steel GX5CrNi19-10, maintaining the welding regimes indicated and using damping layers.

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