RESEARCHES REGARDING THE CAVITATION EROSION RESISTANCE OF THE AUSTENITIC STAINLESS STEEL GX5CrNi 19-10 FROM ZONES RECONDITIONED BY WELDING

IOAN PĂDUREAN*, ILARE BORDEAŞU*, CORNEL VELESCU*, OCTAVIAN OANCA**

The paper continues the previous researches of the author, on the same topic-cavitation erosion- researches which ended with a Ph.D. thesis and through other works..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].

1. INTRODUCTION

The erosion intensity depends on a great variety of factors, such as: the blade material, the suction height, the duration of the phenomenon and the local conditions [2, 3, 4, 5].

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]. 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

* "Politehnica" University of Timişoara
** ISIM – Timişoara

Rev. Roum. Sci. Tech. – Méc. Appl., Tome 52, No. 1, P. 15–26, Bucarest, 2007

can be solved through structural modifications achieved by various heat treatments In this case solution treatment Heat 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 [8, 5].

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 1.

Table 1

Chemical composition and mechanical characteristics

Steel	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	Solution Treatment 1050 ^{0}C/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 [8], at first, the specimens were subjected to solution tratment.

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 Fig. 1.

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

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].

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

4.1. MATERIALS AND PROBES

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 "Specification of the loading procedure through welding" WPS number I.P-01 [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 there were manufactured a cylindrical bar ø20 × 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: = 14 mm.

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 2.

Table 2

The welding regime

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 using the electrodes mark: Selectarc 18.8 Mn Standard: EN 1600: E 18.8 Mn R73;

Chemical composition and mechanical characteristics of electrodes are presented in Table 3.

Table 3

Chemical composition (%) and the mechanical characteristics of the damping layer

C	Mn	Si	Cr	Ni	R_m [Mpa]	$R_{p0.2}$ [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 °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: $p = p_{at}$;
– 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 figures.

5.1. EXPERIMENTAL RESULTS

The cavitation erosion velocities *v* have been obtained, for each attack period Δt, from the mass losses.

The following cavitation erosion characteristic curves have been obtained experimentally (Figs. 2, 3).

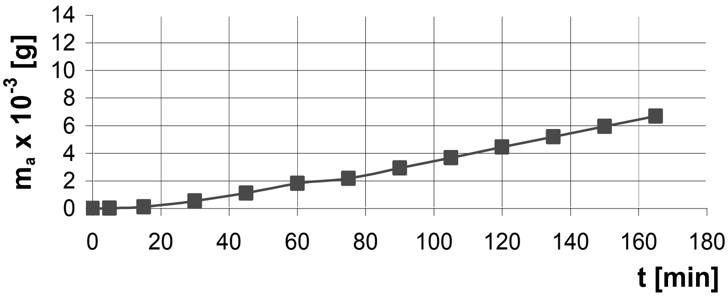


Fig. 2 – Variation in time of the cavitation eroded mass $m_a(t)$.

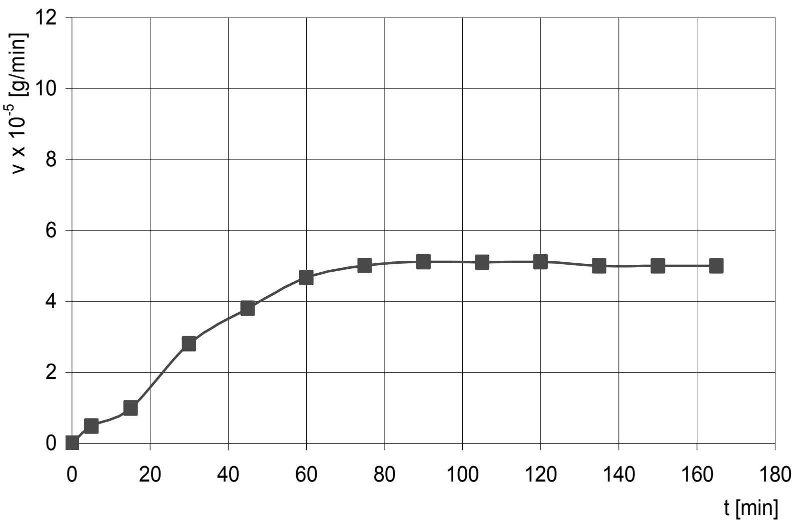


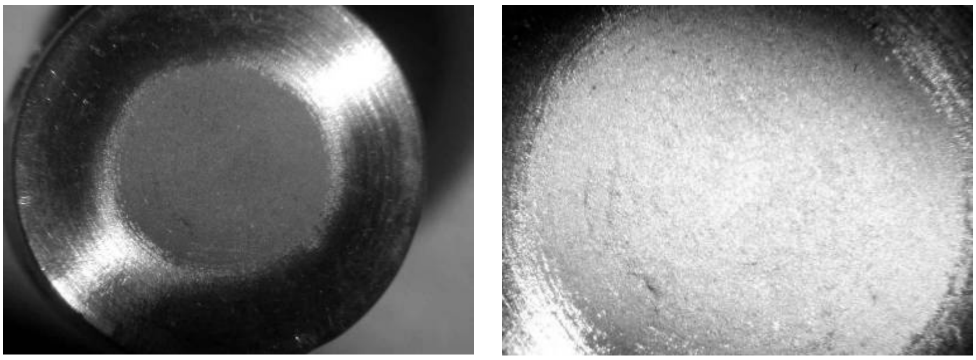
Fig. 3 – Variation in time of the cavitation erosion velocity $v(t)$.

Taking into account the data from Figs. 2, 3 it results that the Austenitic steel GX5CrNi19-10, subjected to the solution treatment, attains after 80 minutes the characteristic cavitation erosion figures: v_s = 5.00 × 10^{-5} g/min and m_a = 6.70 × × 10^{-3} g; the total duration of the test was, of course, 165 minutes.

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.



a b

Fig. 4 – The macroscopic aspect of the steel GX5CrNi19-10 – After the cavitation erosion tests and after heat solution treatment and welding: a) OM 10×; b) OM 20×.
Note: OM 10×, 20× – Optical microscop with 10× or 10× increase factor.

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 (Fig. 4).

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

– a central zone is heavily eroded and presents crakes and microcrakes (Fig. 4b);

– a zone adjacent to the central one has only shallow erosions (Fig. 4a);

– a third zone is also heavily eroded and presents microcrakes (Fig. 4b);

– a fourth zone has only few erosions (Fig. 4a).

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

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 Fig. 5a,b,c,d.

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

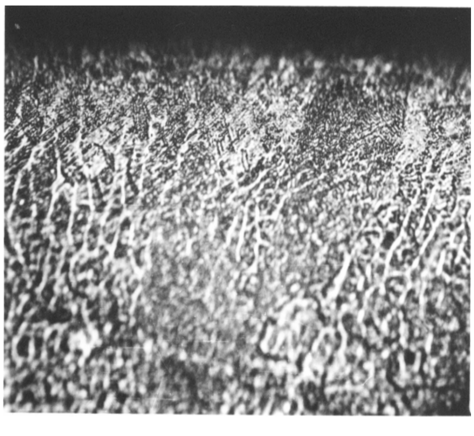
– the devolepment dendritic of the cristalline grains perpeddicular at frontal welder (Fig. 5a,b);

– the fines structure in the thermal influenced zone with the the noumerous fines precipitate intergranular complex carbides (Fig. 5b);

– it appears also a finishing of the granulation in the thermal influenced zone Fig. 5c;

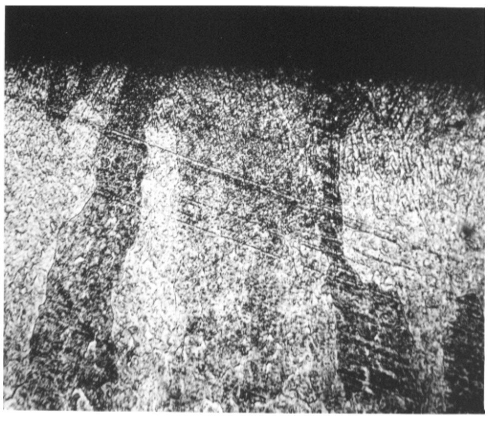
– taking off and the expulsion of some material particles (Fig. 5d);

– breaking up of the crystalline grains, formation the microfissures and the intensification of the separations of complex carbides at the boundaries of the grains (Fig. 5c,d).



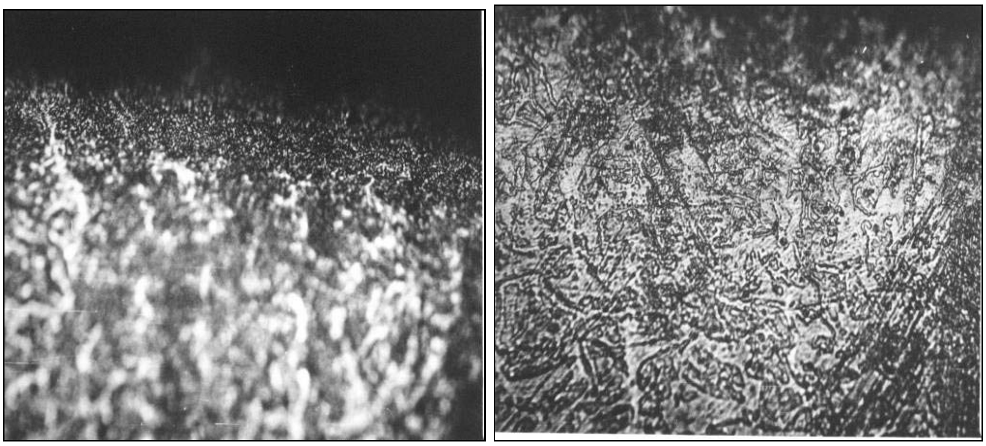
OM 100×

a



OM 500×

b



OM 500× OM 500×

c d

Fig. 5

Note: OM 100×, 500× – Optical microscop with 100× or 500× increase factor.

6.3. MICRO HARDNESS MEASUREMENTS

In the zone unaffected by cavitation (Fig. 6a), 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 (Fig. 6b), at depths until 0.4 mm, it can be seen a malleable deformation of the steel until the HV 0.2 – 240 durities.

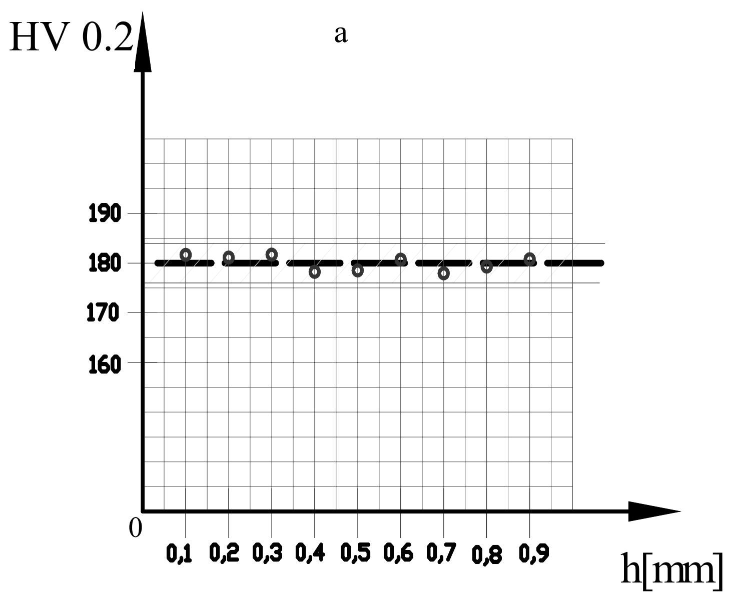
For depths of 0.4 mm until 0.9 mm, the measured durities are HV 0.2 – 190, as for the steel under heat treatment of heat solution treatment.

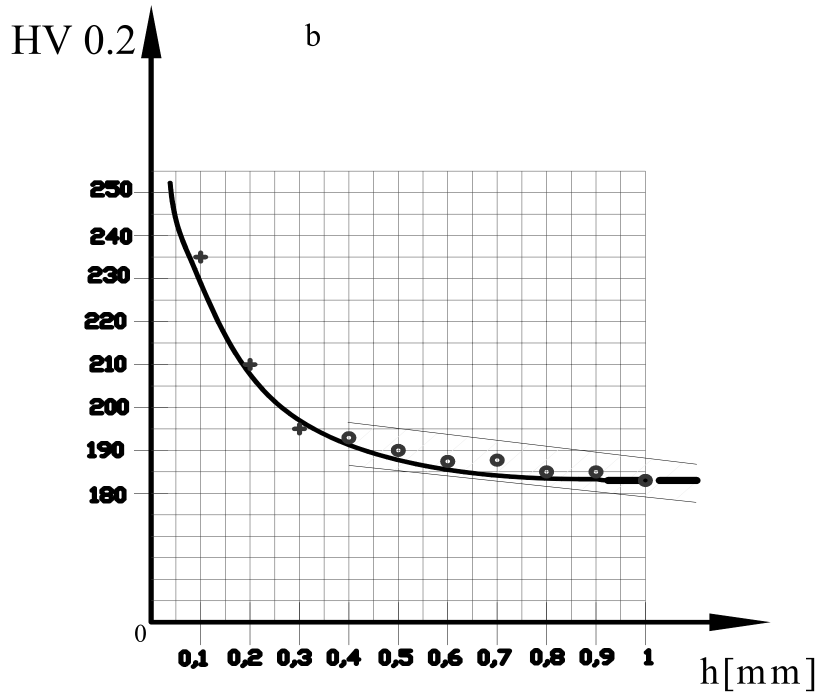
In the most exposed area to the cavitation erosion (Fig. 5c), it can be seen a strong malleable deformation of the steel, the hardness riching in the superficial stratum – HV 0.2 – 330.

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

We supose 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.


HV 0.2
a
190
180
170
160
0
0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9
h[mm]


HV 0.2
b
250
240
230
220
210
200
190
180
0
0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 1
h[mm]

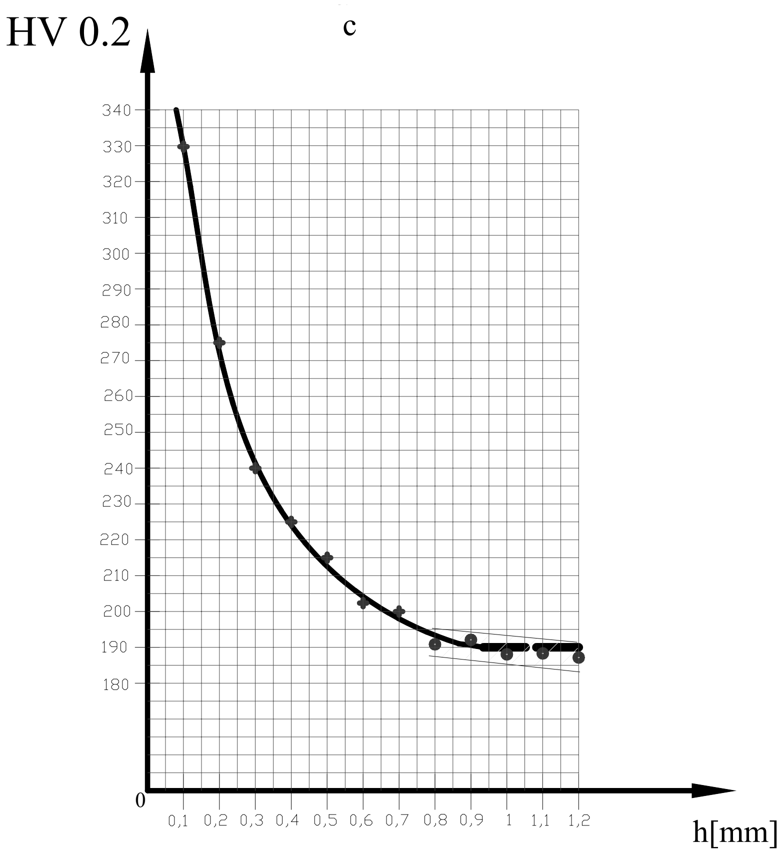


Fig. 6 – Hardness HV0,2-Steel-GX4CrNi 19-10
State: [heat solution treatment and welding].

The same conclusion is obtained from the comparison of the steady state velocities v_s or the final eroded masses m_a of some steels with a good behavior at cavitation [3, 4, 5] (Table 4).

Table 4

Steady state erosion velocity and final eroded masses

Steel mark	$m_a \times 10^3$ g	$v_s \times 10^5$ 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 cavitation erosion of the specimens takes place slowly, gradually and without important craters.

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 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 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/cm^2; the probes tested at cavitation were taken from the thermal influenced zone of the welding.

The obtained steady-state velocity was $v_s = 5.00 \times 10^{-5}$ g/min and the eroded mass was $m_a = 6.70 \times 10^{-3}$ g, fact that confirms a high cavitation resistance of the thermal influenced zone.

The steel GX5CrNi19-10 after solution treatment has $m_a = 13.50 \times 10^{-3}$ g and $v_s = 13.20 \times 10^{-5}$ 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.

Acknowledgement. We wish to express particular thanks to Professor dr. ing. Marin Trușculescu, fellow of Romanian Technical Sciences Academy, for guidance and useful councils during the elaboration of this work.

Received 13 July 2006

REFERENCES

1. ANTON, I., *Cavitaţia*, Vol. I, II, Editura Academia R.S.R., Bucharest, 1984, 1985.
2. KUZMAN A.F., POTENCZ I., TRUŞCULESCU M., MITELEA I., *Rezistenţa la eroziune cavitaţională a unor oţeluri indigene. Influenţa tratamentului termic*, Buletinul Ştiinţific şi Tehnic al Institutului „Traian Vuia" Timişoara, **22(36)**, *1*, 1977.
3. PĂDUREAN I., *Researches upon Cavitation Erosion Resistance of the Heat Treated Stainless Steel GX5CrNi19-10*, Scientific Bulletin of "Politehnica" University of Timişoara, Transactions on Mechanics, Special issue, IXth Edition Timisoara Academic Days International Symposium Engineering Materials New Horizons and Processing Techniques, M.T.P., 2005.
4. PĂDUREAN I., *Researches regarding the cavitation erosion resistance of the martensitic stainless steel from zones reconditioned by welding*, Scientific Bulletin of the "Politehnica" University of Timişoara, Transactions on Mechanics, Special issue, IXth Edition Timişoara Academic Days International Symposium Engineering Materials New Horizons and Processing Techniques, M.T.P, 2005.
5. PĂDUREAN I., *Cercetări asupra măririi rezistenţei la eroziune cavitaţională a rotoarelor de turbină turnate din oţeluri inoxidabile*, PhDThesis, Timişoara, 2005.
6. TRUŞCULESCU M., *Studiul metalelor*, Editura Didactică şi Pedagogică, Bucharest, 1977.
7. TRUŞCULESCU M., IEREMIA, *Oţeluri inoxidabile şi refractare*, Editura Facla, 1983.
8. ** * **, *Oţeluri turnate rezistente la coroziune*, SR EN 10283/1999.
9. ** * **, *Standard method of vibratory cavitation erosion test*, ASTM, Standard G32-85.