# ABOUT CAVITATION EROSION RESISTANCE OF THE MARTENSITIC STAINLESS STEEL FROM ZONES RECONDITIONED BY WELDING

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## ABSTRACT

Paper presents the researches carried on upon the cavitation erosion of martensitic stainless steel GX4CrNi 13-4 (SR EN 10283/99) [1] used for manufacturing Kaplan runner blades. The research is focused on the thermal influenced zones subsequently of the welding process performed in the repair work.

## KEYWORDS

Cavitation, erosion, thermal influenced zone, vibratory device, welding, erosion velocity.

## 1. INTRODUCTION

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. 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.

For Kaplan turbines there are two distinct ways in which cavitation is produced. "The hydrofoil cavitation" occurs as result of the reduction of pressure on the suction side. The erosion is shallow but extended on a large area. Such eroded zones can be seen near the entrance and trailing edges. "The gap cavitation" occurs at the interstice between its external edge and the turbine chamber, being produced by the whirl formed downstream the gap. The erosion is deep but its area is very restricted.

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].

## 2. MATERIALS USED FOR CASTING KAPLAN TURBINE BLADES

The materials used for manufacturing turbine elements must fulfil 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 figure 1. A compromise must be found between the hardness and the tenacity. This problem can be solved through structural modifications achieved by various heat treatments [6], [7]. Simultaneously the chosen variants of heat treatment must assure an increase of the resistance to corrosion, erosion and fatigue. In the industrial practice it can be seen a clear trend to use stainless steels with martensitic or austenitic-martensitic structure [2], [3], [4], [5].

In our country for manufacturing Kaplan turbine blades or Francis impellers there are used the materials presented in table no. 1, [3], [4], [5].

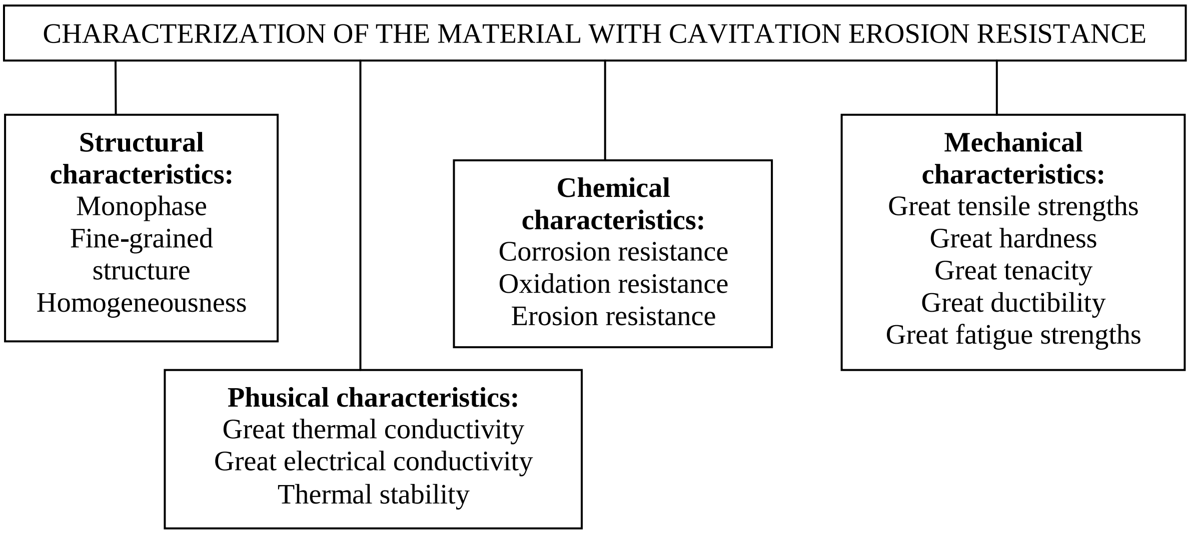



Figure no. 1 Characterization of the material with cavitation erosion resistance

Table no. 1

| Materials used for manufacturing hydraulic turbines | | | |
|---|---|---|---|
| No. | Steel mark | Manufactured elements | Structure<br>A- Austenite,<br>M-Martensite, F-Ferrite |
| 1 | T07CuMoMnNiCr165-Nb | Runners and blades | 40%M+40%A +20%F |
| 2 | T09CuMoMnNiCr185-Ti | Runners and blades | 60%A+10%M+30%F |
| 3 | GX5CrNi13-4 | Runners and blades | M |
| 4 | GX5CrNiMo13-6-1 | Runners and blades | M |

The austenitic and martensitic stainless steels commonly used for manufacturing hydraulic machinery elements, having good cavitation erosion resistance are presented in table no. 2, SR EN 10283/99 [1].

Table no. 2

| Chemical composition (analyses made on liquid steel) (percentage in masses) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Symbolization | | C max | Si max. | Mn max. | P max. | S max. | Cr | Mo | Ni | Structure |
| | Alpha numerical | Numerical | | | | | | | | | |
| 1 | GX4CrNi13-4 | 1.4317 | 0,06 | 1,00 | 1,00 | 0,035 | 0,025 | 12,00..13,50 | Max 0,70 | 3,5..5,00 | martensitical |
| 2 | GX4CrNiMo16-5-1 | 1.4405 | 0,06 | 0,80 | 1,00 | 0,035 | 0,025 | 15,00..17,00 | 0,70..1,50 | 4,0..6,0 | |
| 3 | GX4CrNiMo16-5-2 | 1.4411 | 0,06 | 0,80 | 1,00 | 0,035 | 0,025 | 15,00..17,00 | 1,50..2,00 | 4,0..6,0 | |
| 4 | GX5CrNi19-10 | 1.4308 | 0,07 | 1,50 | 1,50 | 0,04 | 0,03 | 18,00..20,00 | - | 8,00..11,00 | austenitica |
| 5 | GX5CrNiNb19-11 | 1.4552 | 0,07 | 1,50 | 1,50 | 0,04 | 0, 03 | 18,00..20,00 | - | 9,00..12,0 | |
| 6 | GX5CrNiMo19-11-2 | 1.4408 | 0,07 | 1,50 | 1,500 | 0,04 | 0,03 | 18,00..20,00 | 2,00..2,50 | 9,00..12,00 | |

## 3. TESTED MATERIAL

The specimens tested to cavitation erosion are manufactured from the Martensitic stainless steel GX4CrNi13-4 (sr en 10283/99) [1] after a quenching and tempering treatment. The chemical composition and the mechanical characteristics determined on prismatic samples are presented in table no. 3.

Table no. 3

| Chemical composition and mechanical characteristics | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Steel mark | Status | Chemical composition % | | | | | | | | Mechanical characteristics at 20ºC | | | | |
| | | C | Si | Mn | P | S | Cr | Ni | Mo | $Rp_{0,2}$ MPa | Rm MPa | A5% | KVJ | HB |
| GX4CrNi 13-4 1.4317 | Q+T (Quenching and Tempering, volume treatments) | 0,02 | 0,47 | 0,56 | 0,010 | 0,06 | 13,1 | 4,4 | 0,55 | 623 | 800 | 20 | 50 | 270 |

The tests on the steel GX4Cr Ni13-4 have been made on parallelepiped samples 30x30x60 mm. From the same parallelepiped samples, submitted to the loading through welding, have been manufactured the cavitation test samples. According to the SR EN 10283/99 [1,6-7] the prismatic samples were subjected to the following heat treatment, before welding:

| | | | |
|---|---|---|---|
| Quenching temperature | $T_Q$ = 1.050ºC | Tempering temperature: | $T_T$ =650ºC |
| Maintaining time at the high temperature: | tm = 1 hour | Maintaining time at the high temperature: | tm = 3 hours |
| Quenching agent: | water | Tempering agent: | air |

On the specified steel there have been carried out structural analyses on samples metallographic prepared according to [8], [9], [10], [11]. For the metallographic examination it was used an optical microscope provided with a camera. In figure no. 2 there is presented the microstructure of the heat treated steel.

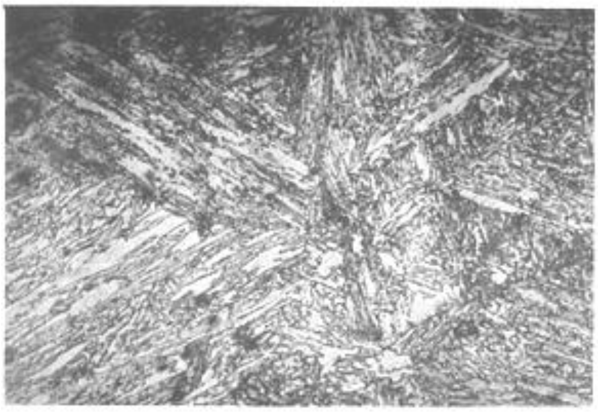


Figure no. 2 The microstructure of the steel GX4CrNi13-4;
OM 500x

After the heat treatment the steel presents:

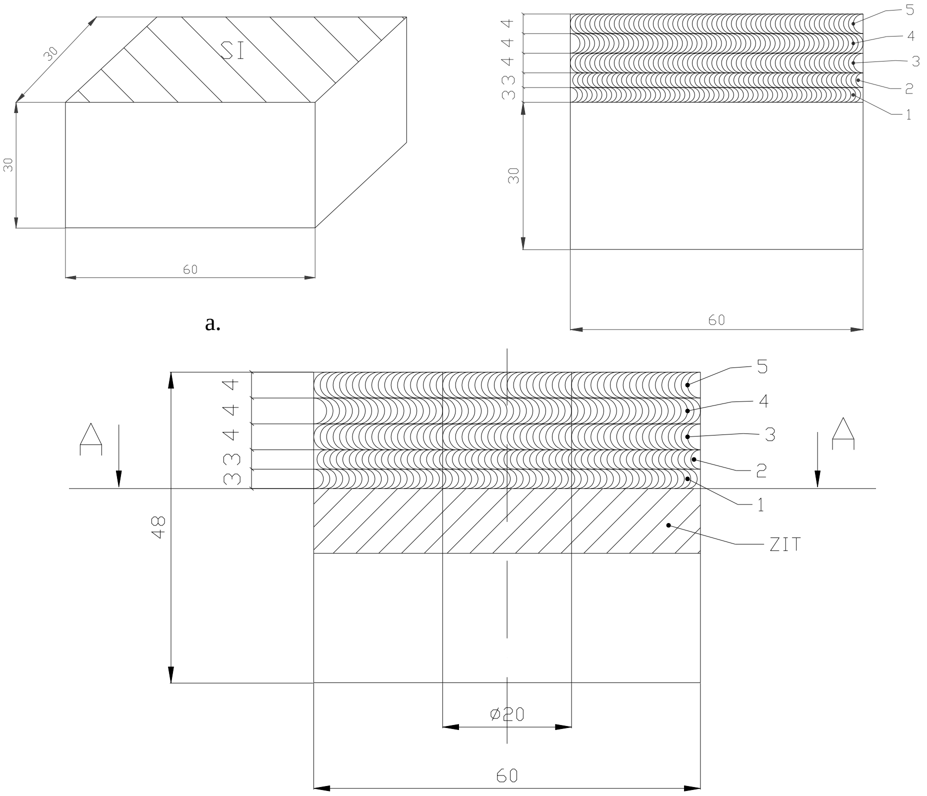
- the granulometric indices G = 8, according to the ASTM standards;
- the structure is: tempered Martensite with fine carbides uniform distributed.

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

### 4.1 Materials and probes

The parallelepiped samples, figure no. 3a 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-02 there would be put down martensitic stainless steel, on the parallelepiped probes 30x30x60 mm, five welded layers: two damping and three against cavitation, figure no. 3b. From the parallelepiped bar loaded with those five welded There were manufactured a cylindrical bar Φ 20x48 mm, figure no. 3c. The thermal influenced zone was rendered evident through an attack with the reactive NITAL [11].

The semi-finished piece was cut from the boundary “base metal-welded metal” (cross section A-A, figure no. 3c), and finally it was obtained the sample d = 14 mm.




a. b. c.

Figure no. 3 The samples dimensions

## 4.2 The loading through welding

The welding procedure is electrical with covered electrodes. The temperature of preheating is T1=120°C.The temperature between the layers was T2=150°C. The welding regime and the electrodes dimensions are presented in table no. 4. The loaded metal (electrodes) are presented in table no. 5.

Table no. 4

| 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 | Φ3,2 | 90-100 | 23-25 | DC$^+$ | 10-12 | 10.350-15.000 | damping |
| 3-5 | Φ4 | 120-130 | 24-26 | DC$^+$ | 12-15 | 11.520-16.900 | against cavitation |

Table no. 5

| Version | Electrodes Mark | Standard | Observations |
|---|---|---|---|
| For the damping layer | Selectarc 18.8 Mn | EN 1600: E 18.8 Mn R73 | Chemical composition (%) of the damping layer and hardness (Table no. 6 ) |
| Cavitation protection layer | UTP 730 | DIN 8555; E7-UM-250-KPR | Chemical composition (%) and hardness of the cavitation layer (Table no. 7 ) |

Table no. 6

| C | Mn | Si | Cr | Ni | HB |
|---|---|---|---|---|---|
| 0,10 | 5.0 | 0.8 | 18,0 | 8,5 | 180 |

Table no. 7

| C | Mn | Si | Cr | Ni | Mo | Co | HB |
|---|---|---|---|---|---|---|---|
| 0,20 | 9,0 | 2,0 | 16,0 | 0,5 | 0,5 | 13 | 250 |

Between two successive repair works, a great importance for the turbine running has the behaviour 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.

### 4.3 Researches upon the cavitation erosion of the specimens manufactured from GX4CrNi13-4

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: [3],[13], [14]:

- vibration amplitude: A = 94 μm;
- frequency: f = 7000±3 Hz;
- pressure at the liquid surface: p = pat;
- 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.

### 4.4 EXPERIMENTAL RESULTS. TESTINGS. MICROSCOPICAL STRUCTURES INTERPETATIONS

The cavitation erosion velocities vs have been obtained, for each attack period Δt, from the mass losses $\Delta m_a(t)$, using the relation:

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

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

- Variation in time of the cavitation erosion velocity v(t), figure no. 4.
- Variation in time of the cavitation eroded mass ma(t), figure no. 5;

Observation: The value $m_a$ in the “Test Bulletin” is obtained by averaging the mass losses of the three tested specimens.

TESTING BULLETIN

Magnetostrictive facility with nickel tube
Material: stainless steel GX4CrNi13-4
Test liquid: distilled water
Control amplitude: 94μm
Mean frequency: 7000±3% Hz
Temperature of the working liquid: 20±1ºC.

| Time [min] | Mass $m_a x10^3$[g] | Velocity $vx10^5$ [g/min] |
|---|---|---|
| 0 | 0,00 | 0,00 |
| 5 | 0,10 | 1,50 |
| 15 | 0,37 | 3,12 |
| 30 | 1,24 | 6,45 |
| 45 | 2,41 | 7,14 |
| 60 | 3,49 | 7,20 |
| 75 | 4,50 | 7,20 |
| 90 | 5,58 | 7,20 |
| 105 | 6,71 | 7,20 |
| 120 | 7,79 | 7,20 |
| 135 | 8,87 | 7,20 |
| 150 | 9,95 | 7,20 |
| 165 | 11,03 | 7,20 |

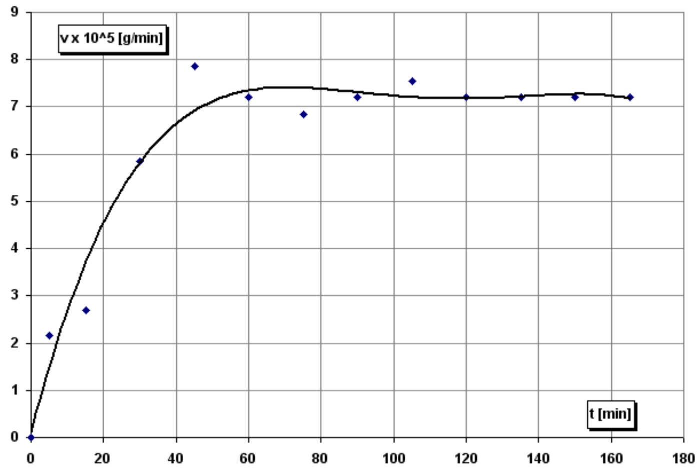


Figure no. 4 Variation in time of the cavitation erosion velocity

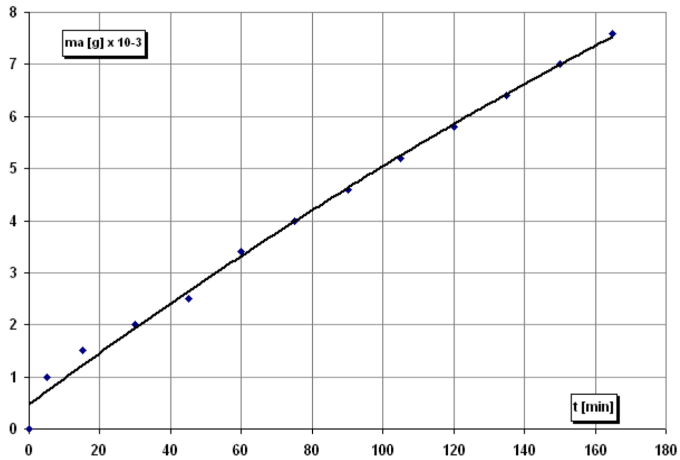
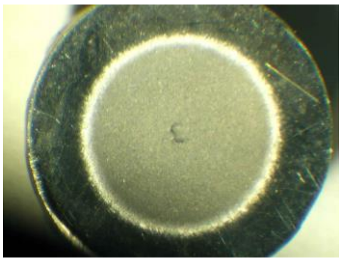


Figure no. 5 Variation in time of the cavitation eroded mass




OM 10X, t=165 min OM 20X, t=165 min

Figure no. 6 The macrostructure of the probes tried at the cavitation

The samples from the stainless steel GX4CrNi13-4, after the cavitation tests were sectioned on the generatrix, prepared and analyzed metallographical. 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 metallographic analysis of the samples subjected to cavitation erosion tests put into evidence the following aspects:

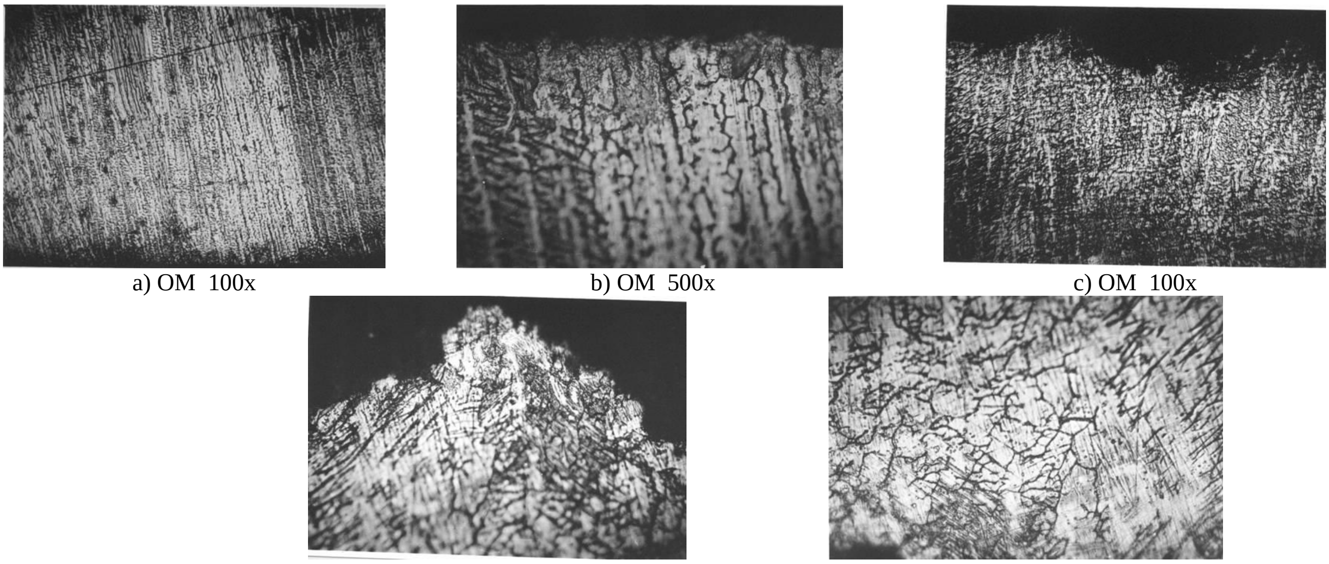
- A dendritic structure of the material loaded through welding, figure no. fig. 7b.
- A structure formed from tempered martensite and complex carbides in the basic metal, figure no. fig.7b .

In the zone damaged by cavitation erosion, the metallographic analysis shows:

- The cavitational attack takes place at the boundaries of the crystalline grains, figure no. 7 c,d.

- Taking off and the expulsion of some material particles, figure no. 7 c, d.
- Breaking up of the crystalline grains and the intensification of the separations of complex carbides at the boundaries of the grains (fig.7 e)
- The appearance of some micro-fissures at the limits of the grains, figure no. 7 c, d.

All these structural aspects show that the cavitation phenomenon produces tensions, great local temperatures that determine the expulsion of material particles and favors diffusion phenomenon which modify the separations of the zonal carbides [16], [17], [18].



a) OM 100x　　b) OM 500x　　c) OM 100x

d) OM 500x　　e) OM 500x

Figura nr. 7 Quenching and Tempering, volume treatments; Thermal influenced areas

The separations of the complex carbide at the boundaries of the grains reduce the corrosion resistance of the steel and produce a tension-creaking corrosion that leads to the expulsion of particles. 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. The same conclusion is obtained from the comparison of the steady state velocities $v_s$ or the final eroded masses ma of some steels with a good behavior at cavitation : [3], [4], [5], [14], [17], table no. 8.

Table no. 8

| Steady state erosion velocity and final eroded masses | | |
|---|---|---|
| Steel mark | $m_a$ x$10^3$<g> | $V_s$ x$10^5$<g/min> |
| GX4CrNi13-4 | 7.60 | 7.00 |
| 40Cr10 | 45.00 | 35.00 |
| GX5 CrNiMo13-6-1 | 32.00 | 22.00 |
| T07CuMoMnNiCr165-Nb | 14.50 | 13.60 |
| T09CuMoMnNiCr185-Ti | 15.00 | 15.00 |

## 5. CONCLUSIONS

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 GX4CrNi13-4, using for the damping layers the electrodes Selectarc 18.8 Mn and for the cavitation layers the electrodes UTP 730.

The welding was made with direct current; the used energies were in the range of 10.350-16.900 J/cm2.

Sensitive to cavitation is the thermal influenced zone.

The probes tested at cavitation were taken from the thermal influenced zone of the welding.

The obtained steady-state velocity was $v_s$=7.00x$10^{-5}$ <g/min> and the eroded mass was $m_a$=7,60 x$10^{-3}$ <g>, fact that confirms a high cavitation resistance of the thermal influenced zone.

The steel GX4CrNi13-4 quenched and tempered has $m_a$=7.60 x$10^{-3}$ <g> and $v_s$=7.00x$10^{-5}$<g/min>.

The metallographic analyses put into evidence the great resistance of the tempered martensite and complex carbides in the thermal influenced zone of the probes submitted to the cavitation tests.

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.

It is recommended to put into industrial practice this repair work procedure, for the blades made from the stainless steel GX4CrNi13-4, maintaining the welding regimes indicated and using damping layers.

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