Researches upon the cavitation erosion behaviour of austenite steels

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Abstract. Paper analyzes the cavitation erosion behavior of two stainless steels with 100% austenitic structure but differing by the chemical composition and the values of mechanical properties. The research is based on the MDE(t) and MDER(t) characteristic curves. We studied supplementary the aspect of the eroded areas by other to different means: observations with performing optical microscopes and roughness measurements. The tests were done in the T2 vibratory facility in the Cavitation Laboratory of the Timisoara Polytechnic University. The principal purpose of the study is the identification of the elements influencing significantly the cavitation erosion resistance. It was established the effect of the principal chemical components (determining the proportion of the structural components in conformity the Schäffler diagram) upon the cavitation erosion resistance. The results of the researches present the influence of the proportion of unstable austenite upon cavitation erosion resistance. The stainless steel with the great proportion of unstable austenite has the best behavior. The obtained conclusion are important for the metallurgists which realizes the stainless steels used for manufacturing the runners of hydraulic machineries (turbines and pumps) with increased resistance to cavitation attack.

1. Introduction

As a rule, the heavy equipments of the hydraulic machineries running in cavitation conditions are manufactured from martensitic stainless steels and for repair works there are used electrodes with austenitic structure because those steels can be easy welded. This situation is a result of economic reasons, the austenitic steels containing large amounts of nickel and chromium, which are very expensive elements [1], [3], [7]. The present work analyzes the cavitation erosion behavior of austenitic steels through different methods: characteristic curves MDE, MDER, microscopic aspects and roughness measurements of the eroded areas. As austenitic materials, there were chosen the steels **X15CrNiSi25-20 şi X5CrNiMo17-12-2** frequently used in manufacturing the electrodes used for welding the damaged areas. These two steels have a complete austenitic structure but different mechanical properties because of differences in the chemical composition. For the laboratory researches was used a laboratory facility with piezoelectric crystals realized by respecting the ASTM-G32 Standard.

2. Researched materials

The materials researched are stainless steels with austenite structure. In conformity with the European Standards the symbols used for theses steels **X15CrNiSi25-20** and **X5CrNiMo17-12-2.** The researched specimens were manufactured from round rolled iron bars. The chemical composition and mechanical properties certified by the manufacturer are:

- for the steel **X15CrNiSi25-20:** <0.15%C, 24-26%Cr, 19-21%Ni, 1.5-2.5%Si, ≤2%Mn, ≤0.045%P, ≤0.015%S, the rest being iron; Rm = (500-700) MPa, $Rp_{o,2} \approx 230$ MPa, Brinell hardness (HB) ≈ 223 daN/mm^2;
- for the steel **X5CrNiMo17-12-2**: <0.08%C, 16.5-18.5%Cr, 10-13%Ni, <1.0 %Si, <2.0 %Mn, ≤0.045%P, <0.03%S, 2-2.5 % Mo, 2-3 %N; Rm = (530-680) MPa, $Rp_{o,2} \approx 240$ MPa, Brinell hardness (HB) ≈ 191 daN/mm^2;

The recorded values for the chemical composition and mechanical properties, established in the Materials Laboratory are:

- for the steel **X15CrNiSi25-20:** 0.095%C, 25.20%Cr, 20.47%Ni, 2.45%Si, 1.67%Mn, 0.044%P, 0.013%S, 0.001% Mo, 0.002%Al, 0.001%Co, 0.001%Cu, 0.001% Ta, the rest being iron; Rm = 580MPa, $Rp_{o,2} = 236$MPa, Brinell hardness (HB) = 228 daN/mm^2;
- for the steel **X5CrNiMo17-12-2**: 0.036%C, 16.515%Cr, 10.105%Ni, 0.689%Si, 0.591%Mn, 0.009%P, 0.015%S, 0.206% Mo, 2.59%N, 0.027%Al, 0.069%Co, 0.165%Cu, % Ta, 0.012%Ti, 0.019%Nb, 0.025%V, 0.084%W, 0.001%B, 0.0260 %As the rest being iron; Rm = 566MPa, $Rp_{o,2}$ = 241MPa, Brinell hardness (HB) = 197daN/mm^2.

The steel **X15CrNiSi25-20** has better mechanical parameters than **X5CrNiMo17-12-2**. So, it is expected a small superiority of **X15CrNiSi25-20** at cavitation erosion.

To establish the microstructure constitution, the equivalents of Chromium (CrE) and Nickel were determined by using the relations (1):

$$Cr_e = \%Cr + 1,5x\%Si + \%Mo + 0,5x\% \cdot (Ta + Nb) + 2x\%Ti + \%W + \%V + \%Al$$

(1)

$$Ni_e = \%Ni + 30x\%C + 0,5x\%Mn + 0,5x\%Co$$

In Table 1 is presented the structural constitution, established from the Schäffler diagram (Figure1), taking into account the computed values for CrE and NiE [3].

To compare the cavitation erosion resistance of the tested steels we chose the Russian martensitic stainless steel **OH12NDL** used in Romania for manufacturing numerous hydraulic turbines. In the condition of the Iron Gates I Power Plant the blades manufactured from **OH12NDL** resisted more than 10000 running hours between two successive repair works, during the period 1970-2004. So, in Table 1 and Schäffler diagram is introduced also this stainless steel.

Table 1. Structural constitution of the analyzed steels

Stainless steel	CrE	NiE	Microstructure	Notation
X15CrNiSi25-20	28.879	24.156	100% austenite	A
X5CrNiMo17-12-2	17.716	11.485	100% austenite	B
OH12NDL	13.2	4.45	74% Martensite + 26% Ferrite	C
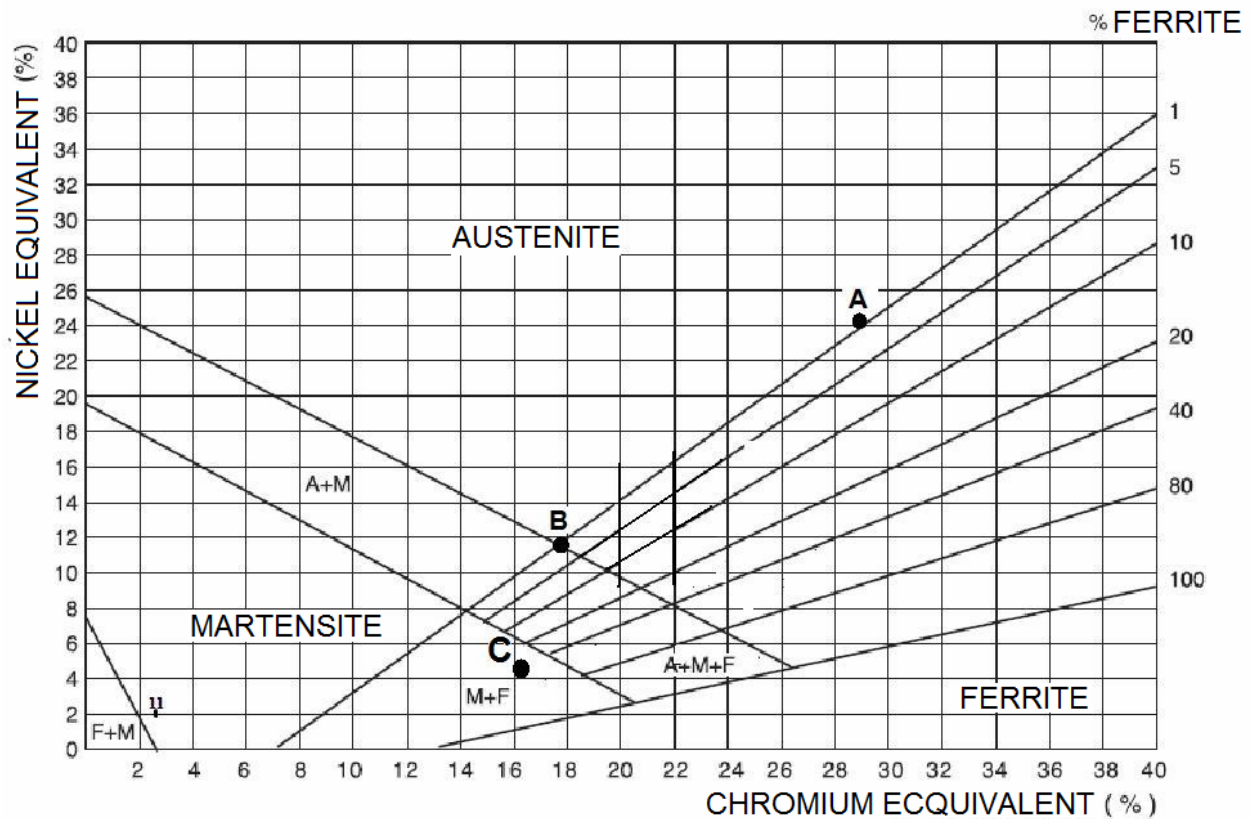
Figure 1. Position of researched stainless steels in the Schäffler diagram
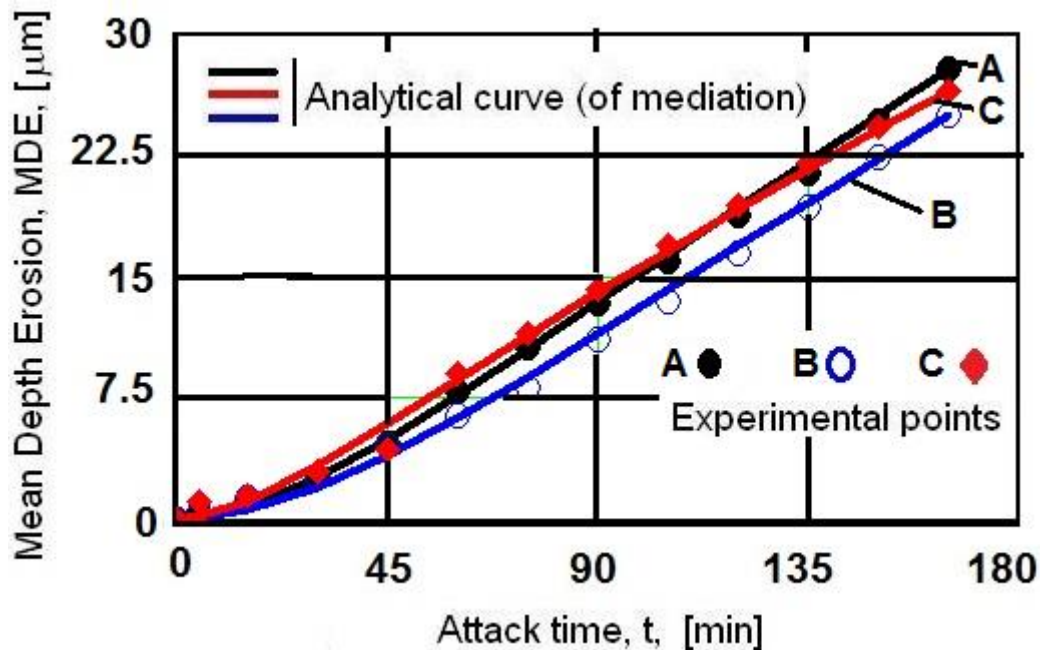**A** - X15CrNiSi25-20; **B** - X5CrNiMo17-12-2; **C**- OH12NDL

3. Test facility and test procedure

For tests was used the vibratory device T2 existing in the Cavitation Laboratory of the Timisoara "Politehnica" University. The facility has piezoelectric crystals [9]. The principal parameters of this facility are: vibration double amplitude 50 μm; vibration frequency 20,000 ± 2% Hz; power of ultrasonic generator 500 W; the power supply voltage 220 V/50 Hz. The device is provided with electronic facilities to maintain constant all the test parameters. In conformity of the ASTM G32-2010 Standard [10], the specimens with a diameter of 15.8 mm were tested in double distilled water at the same exposure time namely 165 minutes divided in 12 testing intervals of 5 minutes (the first one), 10 minutes (the second one) and the rest of for 15 minutes. The total exposure time was extended till the MDER curves became horizontal. Three specimens from each material were tested. The characteristic curves with the average value of those three tested values.

The testing procedure, the specimen preparations, the erosion evaluation after every exposure period and the structural analyze is specific to the laboratory bur integrally respect all the ASTM G32 recommendations [4], [5], [6], [8], [9]. The eroded areas were examined by free eye observations but also by using relevant images with optical and electronic microscopes.

4. Test results. Analyzes and discussions

In Figures 2 and 3 there are given the final results MDE(t) and MDER(t) for the cavitation erosion evolution. The points presented in the diagrams represent the average values for the three values experimentally measured and the curves were obtained by establishing a corresponding exponential equation, using the Bordeasu method [2], [4], [5], [6], [7].

Figure 2. Time evolution of mean depth erosion
Stainless Steel - **A** (**X15CrNiSi25-20**); Stainless Steel - **B** (**X5CrNiMo17-12-2**);
Comparison Stainless Steel - **C** (**OH12NDL)**
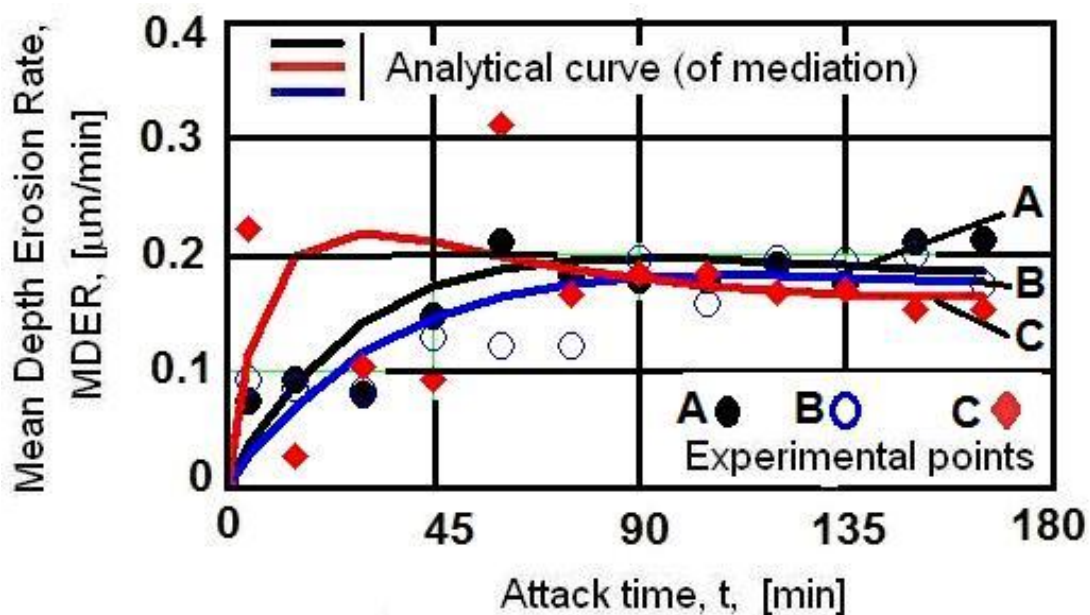
Figure 3. Time evolution of cavitation mean depth erosion rate
Stainless Steel - **A** (**X15CrNiSi25-20**); Stainless Steel - **B** (**X5CrNiMo17-12-2**);
Comparison Stainless Steel - **C** (**OH12NDL)**

The experimental results presented in Figure 2 and Figure 3 show that, in general the three stainless steels have good and very close resistance to cavitation erosion. From Figure 2 we can see that the best performance is given by the steel **B** (**X5CrNiMo17-12-2**); but from Figure 3 it results that the best performance is given by the comparison steel **C** (**OH12NDL**). This difference can be explained by the great mass losses of the steel **C** during the first 60 minutes of tests, after that the behavior is greatly

improved. Our opinion is that the final conclusion must be obtained from the shape of the characteristic curve MDER(t) and not from the final value of the lost mass. Also the steel **B** presents a better resistance than **A**. This can be explained through austenitic condition, very close to the transition line to martensite (see Schäffler diagram). In this zone, the austenite is very unstable and under the impact with the collapsing bubbles is locally transformed in martensite and consequently the local resistance to cavitation is increased.

The eroded surface was analyzed also through microscopy. Supplementary, in the present research there were undertaken analyzes upon the final roughness of the eroded areas. Taking into account all the results the final conclusion was that both austenitic steels can be used for the repair works by welding of the areas eroded through cavitation. The small differences of the behavior are due to the differences of: chemical composition, mechanical properties and metallographic structure. The comparison steel with preponderant martensitic structure has the best resistance.
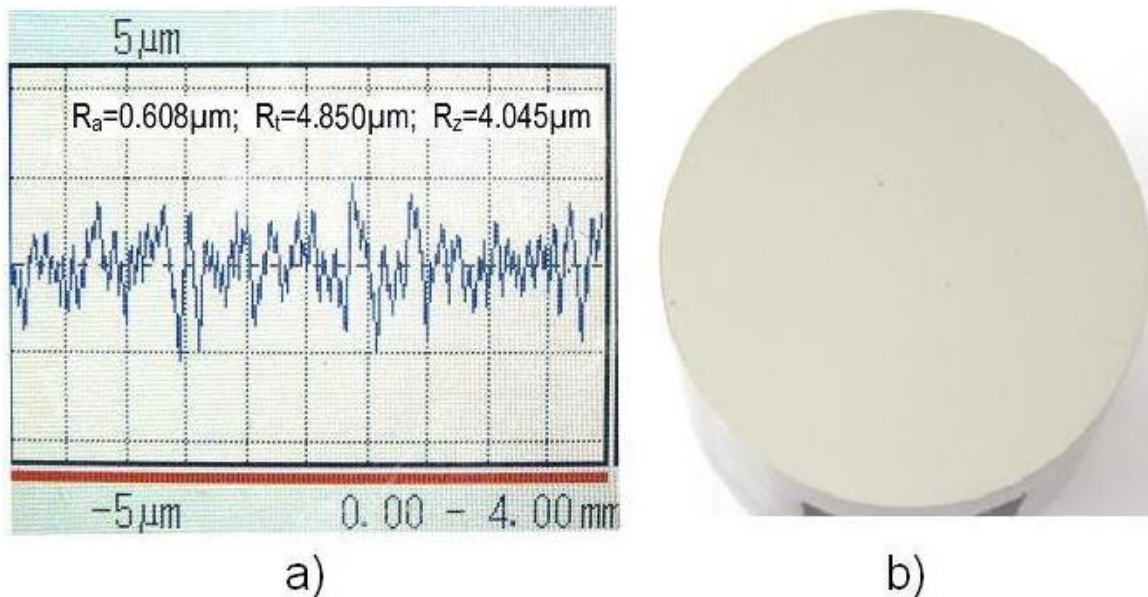
5. Roughness measurements

The roughness of the eroded area present a great interest because the pointed ends of the crests are easy destroyed by the implosion of the cavitation bubbles. With this purpose in mind, the roughness was measured before the beginning and after the end of the tests (165 minutes of exposure). The roughness of the exposed area before the tests is presented in Figures 4 and 5. The surface finishing operations were identical for both materials (**A** and **B**). The small differences between the roughness parameters Ra, Rt and Rz were generated by the material microstructures but can be considered without importance. As a consequence the resistance in the first exposure phase (different MDER) for the studied austenitic steels is determined in principal by the structure and the mechanical parameters and not by roughness. During the cavitation process the smoothness of the surface is modified in a complex way. There appears simultaneously deep indentation but also small degradations. Only these degradations may be considered as roughness. But the measurements can not made distinctions through these two phenomena. On the other hand the MDE(t) values increases constant in time while so roughness measurements can be done only at the end of the cavitation exposure (in our case at 165 minutes).
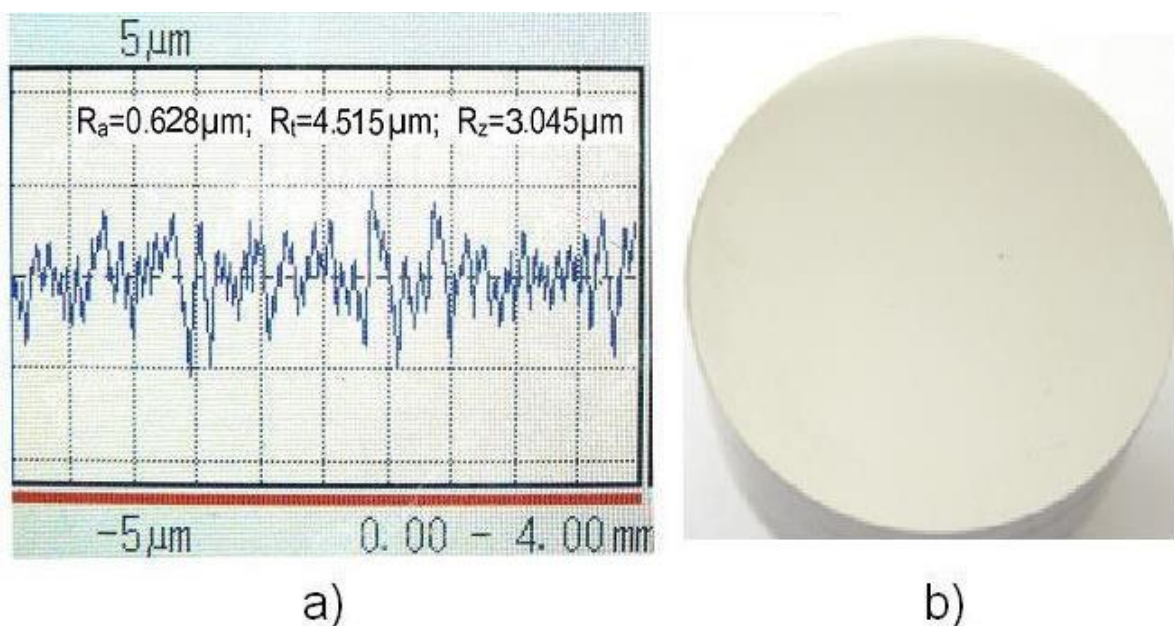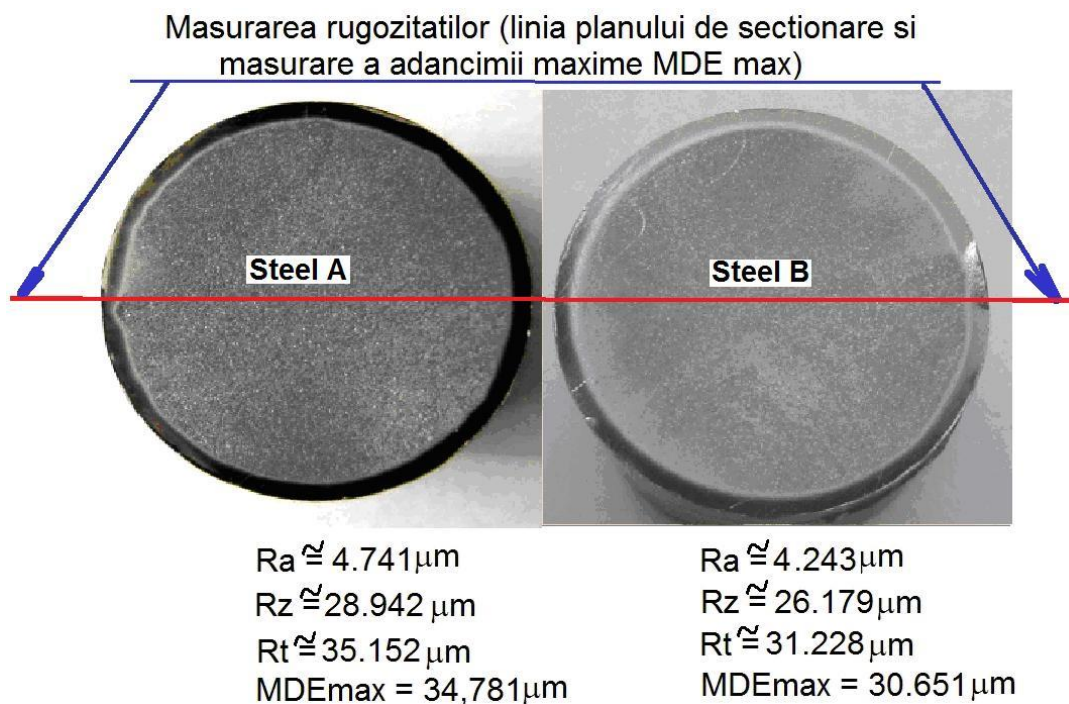

Figure 4. Roughness measurements before cavitation exposure, Steel **A** (**X5CrNiMo17-12-2**)
a) roughness diagram; b) aspect of specimen surface before cavitation exposure

We measured those roughnesses along a single line, with a length of approximate 4 mm, presented in Figure 5. As it can be seen in Figures 9 and 10 the maximum depth was determined on a line with a length of about 0.2…0.5 mm. In conclusion the roughness measurements results simultaneously from the depth of cavitation indentations and the surface lake of smoothness. In order to have estimation between roughnesses and the erosion depths we made such comparisons with h_{max} the maximum depth and MDE_{165} mean depth erosion for 165 minutes of exposure. Figure 6 present the final roughness measurements and the method chosen for measuring the maximum erosion depth.

Figure 5. Roughness measurements before cavitation exposure, Steel **B (X15CrNiSi25-20**)
b)　roughness diagram; b) aspect of specimen surface before cavitation exposure

Masurarea rugozitatilor (linia planului de sectionare si masurare a adancimii maxime MDE max)

Steel A

Steel B

Ra ≅ 4.741 μm
Rz ≅ 28.942 μm
Rt ≅ 35.152 μm
MDEmax = 34,781μm

Ra ≅ 4.243μm
Rz ≅ 26.179μm
Rt ≅ 31.228 μm
MDEmax = 30.651μm

Figure 6. Visual aspect of the tested steels and sectioning plan for maximum depth erosion h_{max}
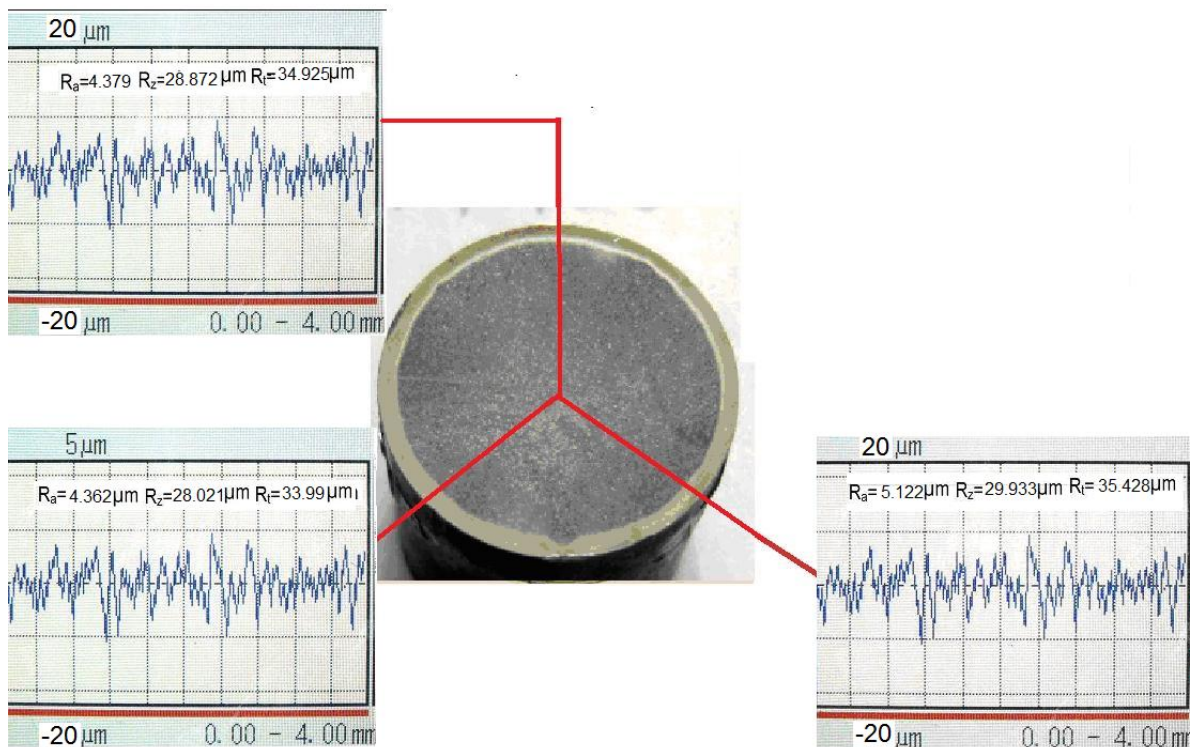
Figure 7. Ra, Rz, and Rt roughness measurements upon three directions (steel **A**)

Even form the visual aspect of the two tested steels, presented in Figure 6, it result a best behavior of the steel **B**. The histograms in Figure 7 and 8 compare the roughness parameters Rz, Rt and Ra with the values MDE_{165}, h_{max} and R_{cav}. The parameter R_{cav} represents the cavitation erosion resistance and is the inverse of the $MDER_{max}$.

It resulted that the values Rz are comparable with MDE_{165} and Rt with h_{max}. It is very probable that this can be made not only for 165 minutes but for all exposure times. Small differences can occur by shifting the positions of the 4 mm measured segment along the diameter.

Regardless of those results and the facility of roughness measurements we do not consider that the use of weight measurements can be avoided and the cavitation erosion roughness can be used as a reliable method for establishing the cavitation erosion behavior.
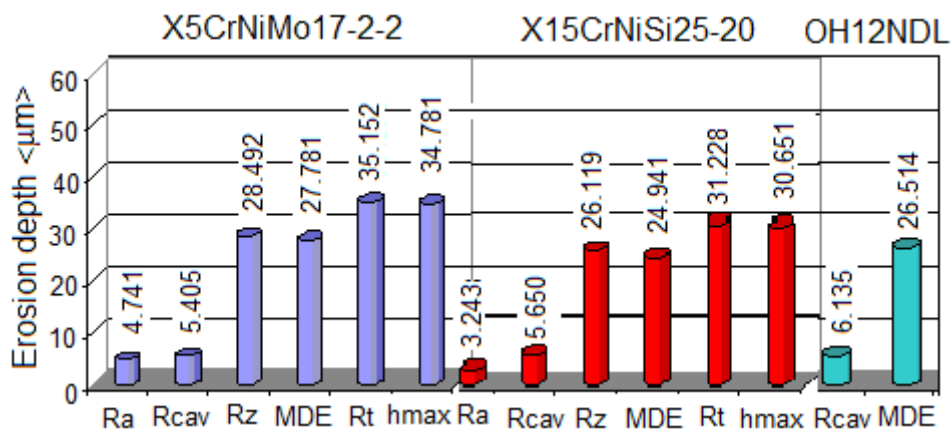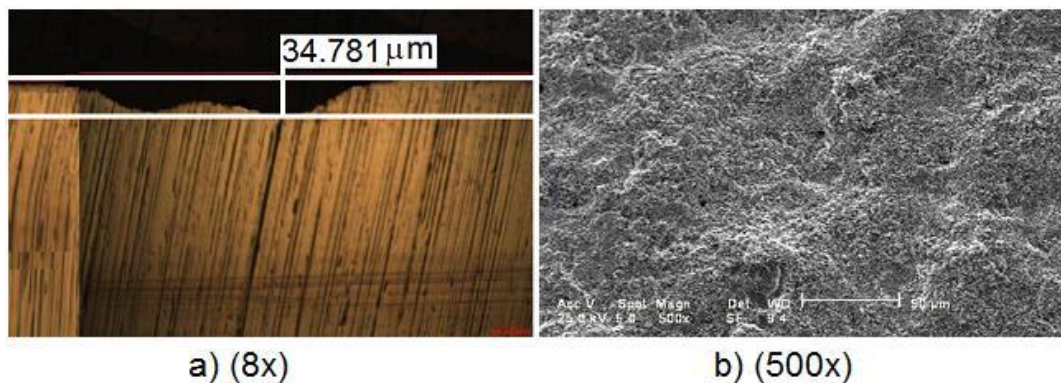

Figure 8. Comparisons between the cavitation erosion characteristic parameters after 165 minutes
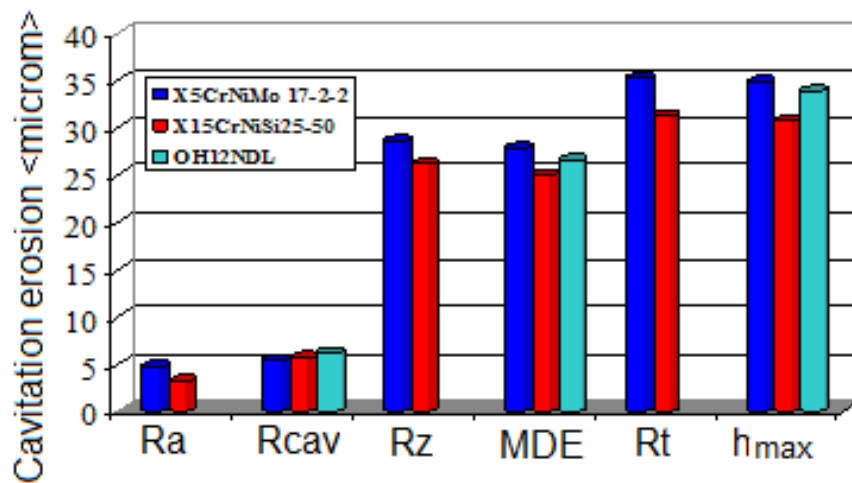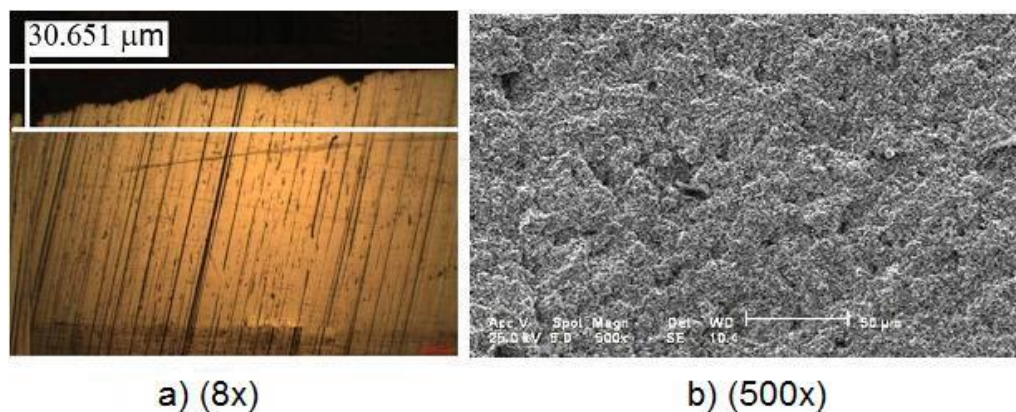
Figure 8. Comparisons regarding cavitation erosion resistance (165 min)

a) (8x)   b) (500x)

Figure 9. Degradation of the cavitation eroded surface– Specimen **A** (steel **X15CrNiSi25-20)**
a)   Maximum depth erosion h_{max}; b) Image of the eroded area

a) (8x)   b) (500x)

Figure 10. Degradation of the cavitation eroded surface– Specimen **B** (steel **X5CrNiMo17-12-2)**
a)   Maximum depth erosion h_{max}; b) Image of the eroded area

The steel **B** (**X5CrNiMo17-12-2**) has a little better cavitation erosion resistance than the steel **A** (**X5CrNiMo17-12-2**) from all methods of comparison characteristic curves (Figures 2 and 3), roughness measurements (Figures 7 and 8) as well as maximum depth of erosion (Figures 9 and 10).

Both austenitic steels are a little weaker than the martensitic steel **C** (**OH12NDL**). Regardless of this superiority the austenitic steels, especially **B** (**X5CrNiMo17-12-2**), are recommended for repair works through welding.

6. Conclusions

a. The characteristic curves MDE(t) and MDER(t) for all three materials are very similar, with a small superiority for the martensitic steels. Regardless of this superiority the austenitic steels, especially **B** (**X5CrNiMo17-12-2**), are recommended for repair works through welding.

b. Even if the mechanical parameters (especially Rm and HB) of the steel **X15CrNiSi25-20** are greater than those for **X5CrNiMo17-12-2**, the cavitation erosion of the last steel is better. This result can be explained by the better structure of the steel **X5CrNiMo17-12-2** containing unstable austenite which under the influence of the bubble implosions is transformed suddenly in martensite.

c. For the researched steels the roughness parameters Rz and Rt, have very close values to MDE_{165} and $h_{max.}$.

d. We consider that in the future those researches must be continued also for other materials. Therw must be choosen also different position of the segment for which roughness measurements are undertaken (appoximate 4 mm).

e. We consider that the use of weight measurements (proposal of ASTM G32 Standard), especially MDE(t) can not be avoided, even if the roughness measurements are very easy to be obtained. The cavitation erosion roughness can be used as a supplementary method for confirmations.

References

[1]   Anton I 1985 *Cavitation*, Tom II, Romanian Academy Publishing House, Bucharest, Romania (in Romanian)

[2]   Bordeaşu I, Popoviciu M O, Balasoiu V and Patrascoiu C 2004 An Analytical Model for the Cavitation Erosion Characteristic Curves, *Scientific Bulletin "Politehnica" University of Timişoara, Transaction of Mechanics* **49**(63) 253-258

[3]   Bordeaşu I 2006 *Cavitation Erosion of Materials,* Timisoara Polytechnic Publishing House, Timisoara, Romania (in Romanian)

[4]   Bordeasu I, Popoviciu M O, Mitelea I, Ghiban B, Ghiban N, Sava M, Duma S T and Badarau R 2014 Correlations between mechanical properties and cavitation erosion resistance for stainless steels with 12% Chromium and variable contents of Nickel, *IOP Conf. Ser.: Mater. Sci. Eng.* **57** 012006

[5]   Bordeasu I, Popoviciu M O, Mitelea I, Ghiban B and Ghiban N 2014 Cavitation erosion resistance of two steels with the same percentage of Chromium and Nickel but different Carbon content, *IOP Conf. Ser.: Mater. Sci. Eng.* **57** 012007

[6]   I Bordeasu, M O Popoviciu, L M Micu, O V Oanca, D Bordeasu, A Pugna and C Bordeasu 2015 Laser beam treatment effect on AMPCO M4 bronze cavitation erosion resistance, *IOP Conf. Ser.: Mater. Sci. Eng.* **85** 012005

[7]   Karabenciov A 2013 *Cercetări asupra eroziunii produse prin cavitaţie vibratorie la oţelurile inoxidabile cu conţinut constant în nichel şi variabil de crom*, Politehnica University of Timisoara, Romania, Doctoral Thesis

[8]   Oanca O, Bordeasu I, Mitelea I and Crăciunescu C 2013 *Phenomenology of Degradation by Cavitation for Heat Treated CuNiAlFe Bronzes*, 22-th International Conference on Metallurgy and Materials, Brno, Czech Republic, May 15-17, pp 1561-1566

[9]   Oanca O, 2014 *Tehnici de optimizare a rezistenţei la eroziunea prin cavitaţie a unor aliaje CuAlNiFeMn destinate execuţiei elicelor navale*, Politehnica University of Timisoara, Romania, Doctoral Thesis

[10]   ***2010 *Standard method of vibratory cavitation erosion test*, ASTM, Standard G32-10