RESEARCH REGARDING THE CAVITATION EROSION RESISTANCE OF THE STAINLESS STEEL WITH 13% Cr AND 4% Ni USED TO MANUFACTURE THE COMPONENTS OF KAPLAN, FRANCIS AND PELTON HYDRAULIC TURBINES

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ABSTRACT

The paper presents the experimental results on testing the cavitation erosion resistance of 2 batch types of the X3CrNi13-4 martensitic stainless steel used to manufacture the components of hydraulic turbines. The experimental research was performed through the stationary specimen method on the cavitation stand of CCHAPT research center from „Eftimie Murgu" University of Resita. The experimental obtained results are shown in tables and graphs regarding the reproduction of the mass loss and cavitation erosion rate function of time curves.

Keywords: *cavitation erosion, martensitic stainless steel, micro-/macrostructure.*

1. INTRODUCTION

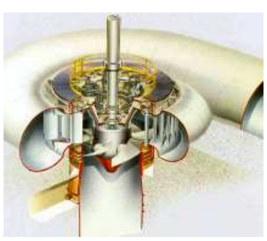
The hydraulic turbines of the hydropower plant structure, are working in the so-called admissible cavitation [1].

Cavitation is a physical phenomenon that occurs inside the liquid while moving. In time it causes damages through cavitation of the metallic materials used to manufacture the hydraulic turbines, pumps or marine propellers [2].

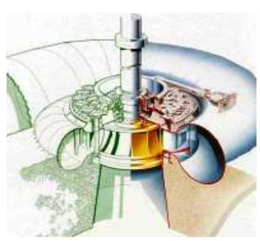
The most commonly used materials to manufacture hydraulic turbines are stainless steels, because they have a good resistance against the cavitation erosion [3, 4, 5].

For the manufacture of Kaplan, Francis and Pelton hydraulic turbines components (like in Fig. 1) is used also the martensitic stainless steel with 13% Cr and 4% Ni for the following [6]:

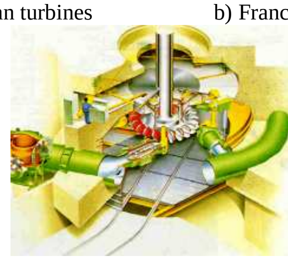
- guide vanes and runner for Kaplan turbines;
- guide vanes, runner and labyrinth seals for Francis turbines;
- nozzle and runner for Pelton turbines.



a) Kaplan turbines



b) Francis turbines



c) Pelton turbines

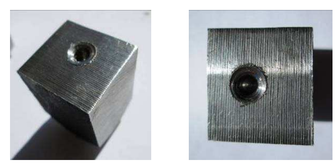
Figure 1 Types of hydraulic turbines according with [6]

The components most affected by cavitation erosion are the runner blades for Kaplan and Francis turbines and for the Pelton turbines are the nozzles.

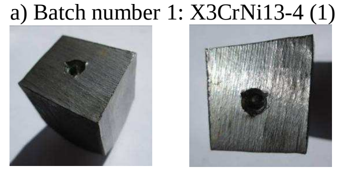
2. THE WORK PROCEDURE

From the runner blades of a hydraulic turbine from a hydropower plant in Romania, were taken two different batches of specimens of the X3CrNi13-4 martensitic stainless steel.

The images of the two specimens are shown in Figure 2, noted as batch number 1 and batch number 2.



a) Batch number 1: X3CrNi13-4 (1)



b) Batch number 2: X3CrNi13-4 (2)

Figure 2 Images of the specimens

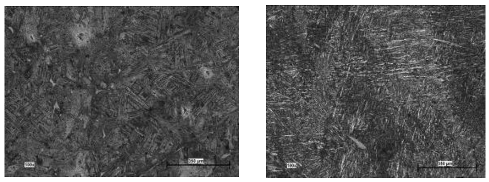
Table 1 shows the chemical composition of the X3CrNi13-4 martensitic stainless steel specimens.

Table 1. The specimens chemical composition [%]

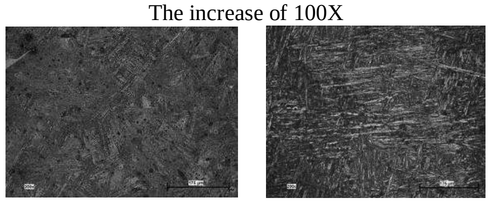
a) Batch: X3CrNi 13-4 (1)	C	Si	Mn	P	S
	0,07	0,41	0,56	0,027	0,014
	Cu	Ni	Cr	Mo	Fe
	0,16	5,17	11,15	0,35	82,08
b) Batch: X3CrNi 13-4 (2)	C	Si	Mn	P	S
	0,06	0,43	0,42	0,015	0,009
	Cu	Ni	Cr	Mo	Fe
	0,07	3,81	12,5	0,32	82,36

From the two specimens, two samples were made in cylindrical form of Φ16 x 10 mm.

Figure 3 shows the microstructure of the 2 batches at 100X and 200X increase before the cavitation, images taken with a metallographic optical microscope.



The increase of 100X



The increase of 200X

a) Batch X3CrNi13-4 (1) b) Batch X3CrNi13-4 (2)

Figure 3 The microstructure of the batches

The cavitation tests were prepared through the stationary specimen method according to the standards and the total cumulated time for each sample subjected to cavitation erosion was 1080 minutes or 18 hours.

This total cumulated time was divided into 36 time periods of 30 minutes, and after each time period by means of a digital balance, the mass of samples and also the loss of eroded material was measured.

3. EXPERIMENTAL RESULTS

From the experimental results were drawn the characteristic cavitation process curves, ie the material loss and cavitation erosion rate versus time curves with the help of XlXtrFun.xll module for the derived calculus which has the dydx (abscissae area - X_i, ordered area - Y_i, derived abscissa) function [7].

3.1 Sample X3CrNi13-4 (1)

Table 2 shows the obtained values for the sample X3CrNi13-4 (1) - batch 1 and figures 4 and 5 shows the graphs for eroded mass and cavitation erosion rate versus time curves.

Table 2. The values for X3CrNi13-4 (1)

Cumulated time	Sample mass	Cum. eroded mass	Cavitation erosion rate
t [min]	m [mg]	m_c [mg]	v_{ec} [mg/h]
0	15007.36	0	0.000
30	15007.16	0.2	0.260
60	15007.1	0.26	0.120
90	15007.04	0.32	0.250
120	15006.85	0.51	0.770
150	15006.27	1.09	1.710
180	15005.14	2.22	2.750
210	15003.52	3.84	4.030
240	15001.11	6.25	4.600
270	14998.92	8.44	4.840
300	14996.27	11.09	5.080
330	14993.84	13.52	5.010
360	14991.26	16.1	5.030
390	14988.81	18.55	5.280
420	14985.98	21.38	5.280
450	14983.53	23.83	5.100
480	14980.88	26.48	5.180
510	14978.35	29.01	5.270
540	14975.61	31.75	5.160
570	14973.19	34.17	5.300
600	14970.31	37.05	5.440
630	14967.75	39.61	5.160
660	14965.15	42.21	5.240
690	14962.51	44.85	5.090
720	14960.06	47.3	5.160
750	14957.35	50.01	5.220
780	14954.84	52.52	5.300
810	14952.05	55.31	5.290
840	14949.55	57.81	5.300
870	14946.75	60.61	5.290
900	14944.26	63.1	4.970
930	14941.78	65.58	5.350
960	14938.91	68.45	5.260
990	14936.52	70.84	5.370
1020	14933.54	73.82	5.470
1050	14931.05	76.31	5.240
1080	14928.3	79.06	5.760

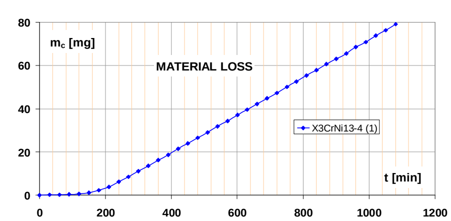


Figure 4 Material loss curve for X3CrNi13-4(1)

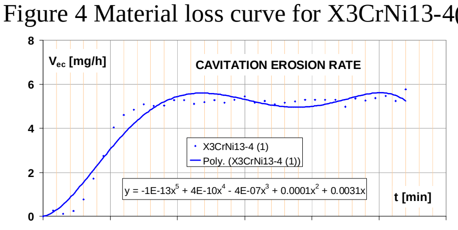


Figure 5 Cavitation erosion rate curve - X3CrNi13-4(1)

3.2 Sample X3CrNi13-4 (2)

In Table 3 are presented the obtained values for the sample X3CrNi13-4 (2) - batch 2.

Table 3. The values for X3CrNi13-4 (2)

Cumulated time	Sample mass	Cum. eroded mass	Cavitation erosion rate
t [min]	m [mg]	m_c [mg]	v_{ec} [mg/h]
0	14759.45	0	0.000
30	14759.41	0.04	0.110
60	14759.34	0.11	0.160
90	14759.25	0.2	0.490
120	14758.85	0.6	1.210
150	14758.04	1.41	2.480
180	14756.37	3.08	3.740
210	14754.3	5.15	4.740
240	14751.63	7.82	5.370
270	14748.93	10.52	5.750
300	14745.88	13.57	5.780
330	14743.15	16.3	5.700
360	14740.18	19.27	5.790
390	14737.36	22.09	5.970
420	14734.21	25.24	6.040
450	14731.32	28.13	5.880
480	14728.33	31.12	5.770
510	14725.55	33.9	5.830
540	14722.5	36.95	6.260
570	14719.29	40.16	6.160
600	14716.34	43.11	6.010
630	14713.28	46.17	5.860
660	14710.48	48.97	5.920
690	14707.36	52.09	5.990
720	14704.49	54.96	6.100
750	14701.26	58.19	6.200
780	14698.29	61.16	6.210
810	14695.05	64.4	6.270
840	14692.02	67.43	6.180
870	14688.87	70.58	6.040
900	14685.98	73.47	6.070
930	14682.8	76.65	6.050
960	14679.93	79.52	5.920
990	14676.88	82.57	5.900
1020	14674.03	85.42	6.070
1050	14670.81	88.64	6.250
1080	14667.78	91.67	5.870

Figures 6 and 7 present the graphs for eroded mass and cavitation erosion rate versus time curves according with the values obtained in Table 3.

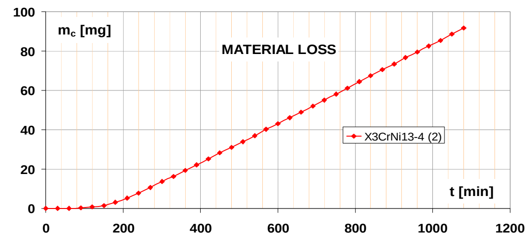


Figure 6 Material loss curve for X3CrNi13-4 (2)

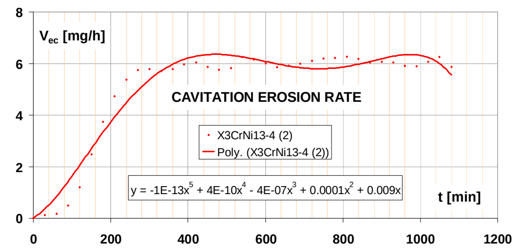


Figure 7 Cavitation erosion rate curve (experimental and analytical) for X3CrNi13-4 (2)

3.3 Comparative study between the analysed samples

Table 4 shows a comparison between value obtained for the 2 samples after the tests for the minimum and maximum eroded mass on period and cumulated, as well for the cavitation erosion rate.

Table 4. Minimum and maximum obtained value

Batch type	Value of eroded mass [mg]		Value of cavitation erosion rate	
	Period	Cumulated	[mg/min]	[mg/h]
Batch 1	0.06	0.2	0.0020	0.120
Batch 2	0.04	0.04	0.0018	0.110
Minimum value				
Batch 1	2.98	79.06	0.0960	5.760
Batch 2	3.24	91.67	0.1045	6.270
Maximum value				

The analytical curves from Figures 5 and 7, were interpolated resulting the polynomial equation 1 (with standard deviation R^2 = 0.9547) and equation 2 (with standard deviation R^2 = 0.9528).

$$v_{ec} = -1 \cdot 10^{-13} \cdot t^5 + 4 \cdot 10^{-10} \cdot t^4 - 4 \cdot 10^{-7} \cdot t^3 + \\ + 0.0001 \cdot t^2 + 0.0031 \cdot t \tag{1}$$

$$v_{ec} = -1 \cdot 10^{-13} \cdot t^5 + 4 \cdot 10^{-10} \cdot t^4 - 4 \cdot 10^{-7} \cdot t^3 + \\ + 0.0001 \cdot t^2 + 0.009 \cdot t \tag{2}$$

Figures 8 and 9 present a comparison between the two batches of the material loss and cavitation erosion rate versus time curves, where the upper curve is characteristic for batch 2 and the lower curve is characteristic for batch 1.

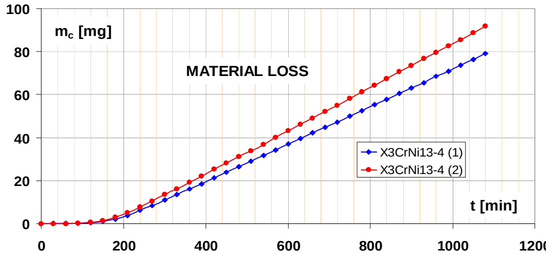


Figure 8 Comparison between the material loss curves for X3CrNi13-4 (1) and X3CrNi13-4 (2)

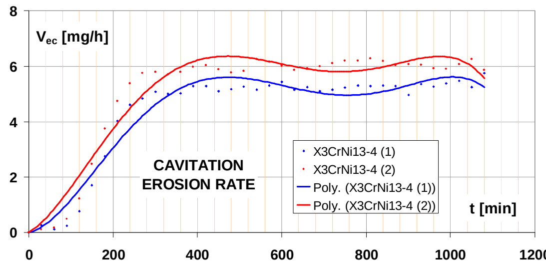
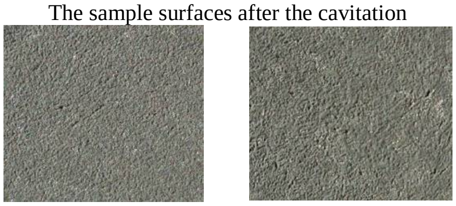


Figure 9 Comparison between the cavitation erosion rate curves for X3CrNi13-4 (1) and X3CrNi13-4 (2)

Figure 10 shows images of surfaces of the two samples before and after the cavitation.

The sample surfaces before the cavitation

The sample surfaces after the cavitation



The macrostructure of sample eroded surfaces

a) Batch X3CrNi13-4 (1) b) Batch X3CrNi13-4 (2)

Figure 10 The surfaces of the samples before and after the cavitation

4. CONCLUSIONS

The following conclusions can be made:

- both curves according to Figures 8 and 9 are similary having the same form, since both samples are from the same X3CrNi13-4 material;
- for the sample 1, the total loss of eroded material was 79.06 mg and for the sample 2, the total loss of eroded material was 91.67 mg, which means that the batch 1 is more resistance than the batch 2, but both batches have a low resistance to the erosion through cavitation, comparative with other materials; the cavitation erosion rate confirm this difference;
- from the sample surfaces images after cavitation, there is a difference between the 2 batches, regarding their cavitation resistance, the difference being due to different proportions of chemical elements values, such as Mn, Cu, Ni and Mo in growth, and Cr and Fe decreasing, that favored cavitation erosion resistance.

5. ACKNOWLEDGMENTS

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