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Study regarding the good cavitation erosion resistance of a 13Cr 4Ni stainless steel used to manufacture the components exposed to water of the hydraulic turbines

This paper presents some theoretical concepts regarding the Francis hydraulic turbines, and also the results of experimental research on cavitation erosion behavior of a 13Cr 4Ni martensitic stainless steel used to manufacture some components of Francis hydraulic turbines. These results are presented in tabular form, through charts and pictures, meant to highlight the properties of this steel.

Keywords: Cavitation erosion, 13Cr 4Ni stainless steel, hydraulic turbines

1. Introduction

Characterized by cavitation bubbles, cavitation phenomenon [1] and [2], may occur in the runners of hydraulic machines, such as pumps and turbines, also by the valve, pipe or other such environments [3].

Therefore, during the time the cavitation phenomenon destroy by cavitation erosion [1] and [3], the materials of the some assembly components which operates in a liquid medium.

In the present also, many metallic materials are tested [4 - 8], on their cavitation erosion resistance [9 - 11].

Tests and experimental research, are made on the experimental stands, such as vibratory apparatus [12] şi [13], that simulates the phenomenon of cavitation and respect certain standards [14] and [15].

In the present paper, with the help of a cavitation stand, through indirect cavitation method [16] and [17], was tested the cavitation erosion behavior of a X3CrNi13-4 martensitic stainless steel used to manufacture some components of Francis hydraulic turbines.

For a X3CrNi13-4 stainless steel, the authors from the same collective, presented some results [12], [18] and [19]. For this stainless steel, the chemical composition is shown in Table 1.

Table 1.

Chemical composition (X3CrNi13-4 stainless steel) [%]									
C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Fe
0.07	0.41	0.56	0.027	0.014	0.16	5.17	11.15	0.35	82.08

2. Hydraulic turbines

According to citation [20], Francis hydraulic turbine is a radial-axial reaction turbine, able to convert hydraulic energy stereo- mechanical energy with maximum efficiency over 90%.

This turbine is now used widely in hydropower plants capitalizing constructive simplicity, robustness and safety in the operation of specific non-adjustable blades runner [21].

Francis hydraulic turbines may be with vertical shaft (Figure 1) or horizontal shaft, both versions with vacuum cleaner crank respectively rectilinear draft tube [20].

To highlight a clearer picture of the construction of a Francis hydraulic turbine and its components, forwards Figure 1 is shows. Also, Figure 2 presents more details on cavitation phenomenon and the cavitation erosion Francis meets at the Francis hydraulic turbines runners [3] and [20 - 22].

The components from Figure 1 are as follows: 1) Spiral case; 2) Stav ring; 3) Guide vane; 4) Runner; 5) Draft tube; 6) Main shaft; 7) Regulating apparatus for guide vanes and 8) Servomotors.

Of these, the runner is the most exposed to cavitation phenomenon and cavitation erosion [20].

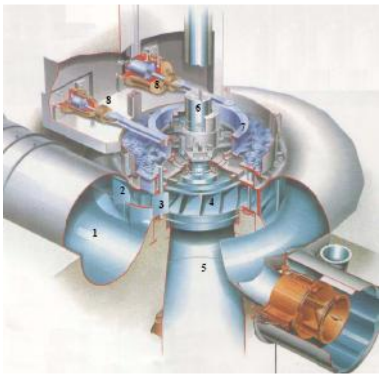
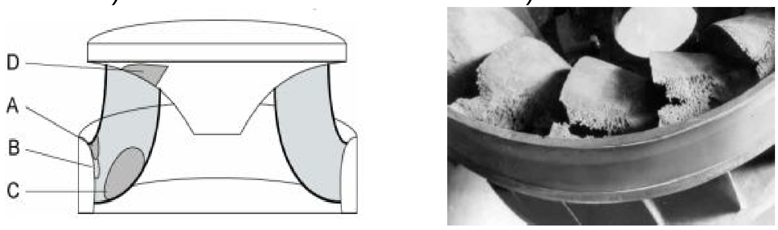


Figure 1. Construction of a Francis turbine (components).

a) slow runner　　　　　　b) normal runner



c) typical areas of erosion cavitation

Figure 2. Characteristic images of Francis hydraulic turbines runners

3. Cavitation stand. Work procedure and research results

For the operation of the experimental stand (Figure 3), it is necessary that the natural frequency to be within the range 20000 ± 500 Hz, the following working conditions: amplitude of 50 μm, used liquid temperature 25 ± 2 °C, and the distance between the used acoustic concentrator and sample 0.6 mm.

Figure 3. Experimental cavitation stand

The work procedure it complies with G32-92 [14] and G32-10 [15] standards. The samples were made in cylindrical form with the dimensions of Φ16x10 mm. For this cavitation erosion experimental research, of the two samples, their four surfaces have been subjected to cavitation attack of 180 minutes, so in total, a time of 720 minutes.

Table 2.

Cumulated time	Time period	Sample mass	Eroded mass		Cavitation erosion rate	
			Period	Cumulated		
t	Δt	m	Δm	m_c	v_{ec}	
[min]	[min]	[mg]	[mg]	[mg]	[mg/min]	[mg/h]
0	0	15142.99	0	0	0.0000	0.000
5	5	15142.98	0.01	0.01	0.0020	0.120
15	10	15142.96	0.02	0.03	0.0012	0.072
30	15	15142.96	0	0.03	0.0007	0.040
45	15	15142.94	0.02	0.05	0.0030	0.180
60	15	15142.87	0.07	0.12	0.0047	0.280
75	15	15142.8	0.07	0.19	0.0090	0.540
90	15	15142.6	0.2	0.39	0.0123	0.740
105	15	15142.43	0.17	0.56	0.0153	0.920
120	15	15142.14	0.29	0.85	0.0180	1.080
135	15	15141.89	0.25	1.1	0.0217	1.300
150	15	15141.49	0.4	1.5	0.0273	1.640
165	15	15141.07	0.42	1.92	0.0360	2.160
180	15	15140.41	0.66	2.58	0.0520	3.120

Table 3.

Cumulated time	Time period	Sample mass	Eroded mass		Cavitation erosion rate	
			Period	Cumulated		
t	Δt	m	Δm	m_c	v_{ec}	
[min]	[min]	[mg]	[mg]	[mg]	[mg/min]	[mg/h]
0	0	15140.73	0	0	0.0000	0.000
5	5	15140.72	0.01	0.01	0.0020	0.120
15	10	15140.7	0.02	0.03	0.0023	0.136
30	15	15140.66	0.04	0.07	0.0017	0.100
45	15	15140.65	0.01	0.08	0.0010	0.060

Cumulated time	Time period	Sample mass	Eroded mass		Cavitation erosion rate	
			Period	Cumulated		
t	Δt	m	Δm	m_c	v_{ec}	
[min]	[min]	[mg]	[mg]	[mg]	[mg/min]	[mg/h]
60	15	15140.63	0.02	0.1	0.0033	0.200
75	15	15140.55	0.08	0.18	0.0060	0.360
90	15	15140.45	0.1	0.28	0.0063	0.380
105	15	15140.36	0.09	0.37	0.0090	0.540
120	15	15140.18	0.18	0.55	0.0130	0.780
135	15	15139.97	0.21	0.76	0.0163	0.980
150	15	15139.69	0.28	1.04	0.0207	1.240
165	15	15139.35	0.34	1.38	0.0243	1.460
180	15	15138.96	0.39	1.77	0.0277	1.660

Table 4.

Cumulated time	Time period	Sample mass	Eroded mass		Cavitation erosion rate	
			Period	Cumulated		
t	Δt	m	Δm	m_c	v_{ec}	
[min]	[min]	[mg]	[mg]	[mg]	[mg/min]	[mg/h]
0	0	14928.78	0	0	0.0000	0.000
5	5	14928.75	0.03	0.03	0.0047	0.280
15	10	14928.73	0.02	0.05	0.0015	0.088
30	15	14928.72	0.01	0.06	0.0003	0.020
45	15	14928.72	0	0.06	0.0023	0.140
60	15	14928.65	0.07	0.13	0.0033	0.200
75	15	14928.62	0.03	0.16	0.0063	0.380
90	15	14928.46	0.16	0.32	0.0113	0.680
105	15	14928.28	0.18	0.5	0.0137	0.820
120	15	14928.05	0.23	0.73	0.0163	0.980
135	15	14927.79	0.26	0.99	0.0220	1.320
150	15	14927.39	0.4	1.39	0.0270	1.620
165	15	14926.98	0.41	1.8	0.0313	1.880
180	15	14926.45	0.53	2.33	0.0393	2.360

Table 5.

Cumulated time	Time period	Sample mass	Eroded mass		Cavitation erosion rate	
			Period	Cumulated		
t	Δt	m	Δm	m_c	v_{ec}	
[min]	[min]	[mg]	[mg]	[mg]	[mg/min]	[mg/h]
0	0	14926.52	0	0	0.0000	0.000
5	5	14926.51	0.01	0.01	0.0017	0.100
15	10	14926.5	0.01	0.02	0.0009	0.052
30	15	14926.49	0.01	0.03	0.0007	0.040
45	15	14926.48	0.01	0.04	0.0003	0.020
60	15	14926.48	0	0.04	0.0043	0.260
75	15	14926.35	0.13	0.17	0.0083	0.500
90	15	14926.23	0.12	0.29	0.0103	0.620
105	15	14926.04	0.19	0.48	0.0113	0.680
120	15	14925.89	0.15	0.63	0.0140	0.840
135	15	14925.62	0.27	0.9	0.0223	1.340
150	15	14925.22	0.4	1.3	0.0263	1.580
165	15	14924.83	0.39	1.69	0.0300	1.800
180	15	14924.32	0.51	2.2	0.0380	2.280

After the test period, depending on obtained results, it will be made the mass loss curves (Figure 4) and cavitation erosion rate versus time curves (figura 5). From these results, presented in Tables 2 and 3 for the two samples, it appears that sides 1 and 2 of the sample 1 lost a weight, each of 2.58 [mg] respectively 1.77 [mg], and the sides 1 and 2 of the sample 2 lost a weight, of 2.33 [mg] respectively 2.2 [mg] each.

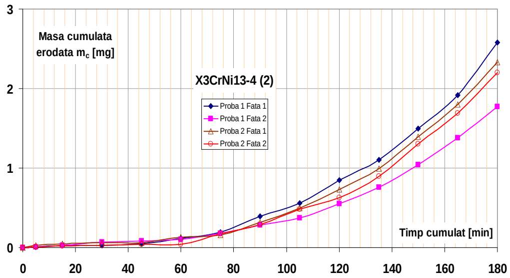


Figure 4. Material loss curves.

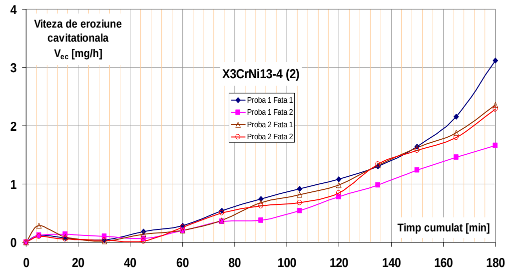
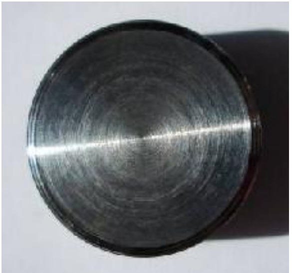
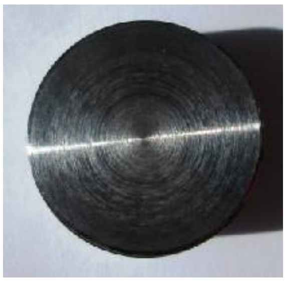
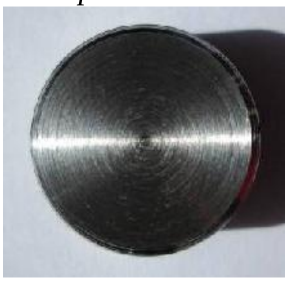


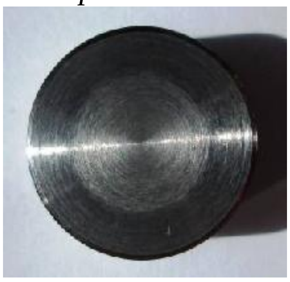
Figure 5. Cavitation erosion rate curves.





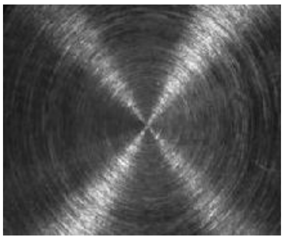
Sample 1 - Face 1 *Sample 1 - Face 2*

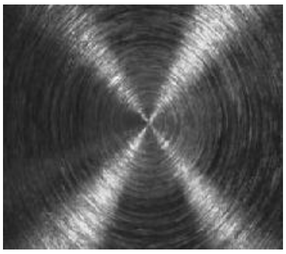




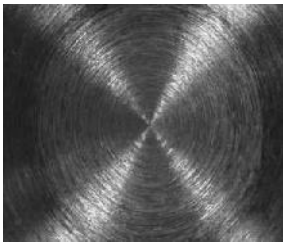
Sample 2 - Face 1 *Sample 2 - Face 2*

Figure 6. Images of the samples before the cavitation





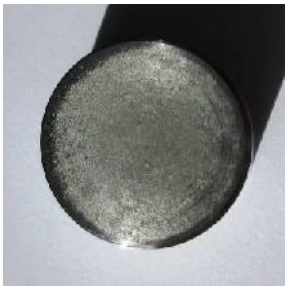
Sample 1- Face 1 *Sample 1 - Face 2*



Sample 2 - Face 1 *Sample 2 - Face 2*

Figure 7. Macrostructures of the samples before the cavitation

Sample 1 - Face 1

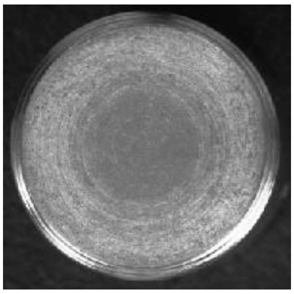


Sample 1 - Face 2

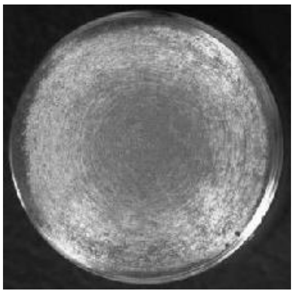
Sample 2 - Face 1

Sample 2 - Face 2

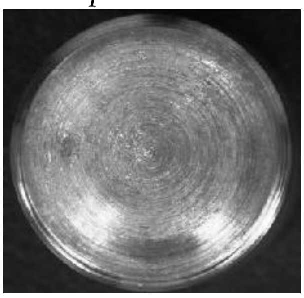
Figure 8. Images of the samples after the cavitation



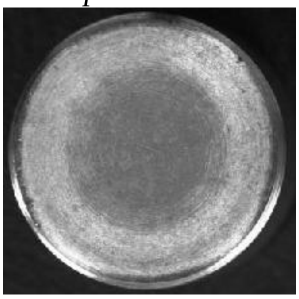
Sample 1- Face 1



Sample 1 - Face 2



Sample 2 - Face 1



Sample 2 - Face 2

Figure 9. Macrostructures of the samples after the cavitation

4. Conclusion

- Of the surfaces 1, 2, 3, 4 belonging the samples 1 respectively 2, the most resistance against cavitation erosion was surface 2 of sample 1 (1.77 mg), and the lowest cavitation erosion was surface 1 of sample 1 (2.58 mg);
- Also, of the four surfaces, regarding the greatest amount the mass lost for a testing standard period, it was as follows: 0.66 mg (S1-S1); 0.39 mg (S1-S2); 0.53 mg (S2-S1) şi 0.51 mg (S2-S2);
- According to other experimental results in some citations of this paper, the X3CrNi13-4 stainless steel, assume a good resistance against cavitation erosion.

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