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Some Laboratory Tests Regarding the X20Cr13 Martensitic Stainless Steel Behaviour

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Abstract. In this paper, beside the documentation regarding the many laboratory tests of X20Cr13 steel, the cavitation erosion, dry sliding wear, hardness respectively corrosion of this martensitic stainless steel was investigate. As cavitation erosion aspects, the authors present some preview results and continue to investigate the cavitation erosion resistance of X20Cr13 steel for an extended duration of 900 minutes of the cavitational attack, duration divided into 30 periods of 30 minutes. All this research through the stationary specimen method was done by using a cavitation stand and the obtained results were presented through cumulative mass loss and cavitation erosion rate versus time curves. As dry sliding wear aspects, the research was done with a CSM Tribometer through the pin-on-disk method and the obtained results were presented by means of the coefficient of friction and the wear rate. As hardness aspects, the measurement was made through the Vickers method using a Zwick/Roell microhardness tester. Finally, as corrosion aspects the research was done with a three-electrode cell using potentiodynamic polarization method and the obtained results were presented as corrosion curve in a logarithmic form.

1. Introduction

Hydraulic machines (hydraulic pumps and turbines) have a certain lifetime, which extends from operation to laying off of works [1,2]. In the case of hydraulic turbines, they can operate over 30 years (over 100.000 hours) [3]. Therefore, during the operation of the hydraulic turbines components is given maintenance and various repairs until the capital repair or refurbishment [4].

A hydraulic turbine requires different components, which are made of different materials, materials that encounter different types of wear and corrosion [5-7]. According to [8], in choosing the materials correctly, they are based on several criteria and requirements as follows: functional, technological, economic and social. For the manufacture of large components of hydraulic turbines, especially steel, cast iron and bronze are used [2]. For example, the rotor of a hydraulic turbine is cast from stainless steel [9]. Several grades of stainless steels are the following 12Cr-4Ni, 13Cr-1Ni, 13Cr-4Ni, 16Cr-5Ni, 18Cr-8Ni, 18Cr-10Ni, steels which must have very good properties for a good cavitation behavior and implicitly against cavitation erosion [10-13].

Like a type of wear, cavitation erosion occurs as a result of the cavitation phenomenon encountered in the liquid medium where the hydraulic turbine rotors work. Different research on the cavitation erosion of materials respectively on the cavitation phenomenon has been carried out by several authors

[14-21]. Also, researches on the hydraulic turbine components reconditioning were made due to its aspects on economics of raw materials, materials and energy [22,23]. For example, in the case of hydraulic turbine rotors, repairs of their damaged surfaces can be done in situ in a hydropower plant, where a modern method is the 3D scanning of the affected area and replaced the empty space with the one deposited by the Rapid Prototyping technique [24]. There are also other different techniques for the rehabilitation of areas affected by different wear types which most often are thermal treatments, coatings deposition, welding repairs and redesign of the components geometry [2].

Welding repair of rotor blades affected by certain imperfections, cracks and cavitation erosion includes several stages, such as: polishing of areas with imperfections of up to 20 mm; eliminate them by milling, drilling or grinding of areas with imperfections greater than 20 mm; application of heat treatment (where it was found that a stress-relief and annealing heat-treatment after welding repair and a heat treatment of the joining is necessary [25-29]; such thermal treatments can be increased by the hardness of the used steels) and finally the visual control with penetrating liquids.

In addition to the use of stainless steels in the casting of hydraulic turbine rotors, they also have a variety of other applications [30-33], such as steam turbines, water and steam valves, or machines working in corrosive environments. In all these areas, wear (cavitation erosion and sliding wear) occur as well the corrosion, corrosion which means the materials deterioration and degradation under the action of chemical agents from the environment, starting from the surface the material [34-37].

In this way, given that wear and corrosion are inevitable phenomena that cause industrial economic losses and in agreement with many research which have been published [38-42], this paper, through many laboratory tests, reports the experimental results regarding the cavitation erosion, dry sliding wear, hardness respectively corrosion of the X20Cr13 martensitic stainless steel.

Regarding the cavitation erosion tests, based on the reference [16] where a part of the authors tested two samples of this X20Cr13 steel for 180 minutes (with periods of 5, 10 and 15 minutes) and obtained for the four surfaces the following material losses: 9.32, 9.25, 10.25 and 8.68 mg; in this paper the authors continue the cavitation erosion tests for an extended time of 900 minutes of cavitation attack only for sample no. 2, surface 4 (surface with less loss) and investigates for the X20Cr13 steel, the dry sliding wear behavior, microhardness and corrosion.

2. Experimental procedure

The laboratory tests were based on the following ASTM and ISO standards: G32-92 and G32-10 standards for cavitation erosion; ASTM G99-95a standard for dry sliding wear; ASTM E384 for the microhardness tests respectively ISO 13129 for electrochemical measurement.

The experimental conditions for the cavitation erosion tests on the cavitation stand (vibratory cavitation apparatus) [43] were: frequency value must set of 20 ±0.5 kHz respectively amplitude of 50 μm; the water container (with distilled water) must be cylindrical with the depth of 100 ±10 mm; the water temperature shall be 25 ± 2°C; the working samples shall have a diameter of 15.9 ± 0.05 mm and the sample surface must be smooth. Cavitation erosion resistance testing on the experimental stand can be done by two methods: direct cavitation (for a short time) or indirect - stationary specimen method (slower process). For this, the used method is the second one, and each sample was tested for 30 minutes. Horn and sample are both immersed in the water container and the cavitation bubbles are generated by the horn (sonotrode) above the samples at 0.6 mm distance. At end of the experimental procedure, each sample was weighed with a digital balance to measure the material loss.

To determine the dry sliding wear resistance, the CSM Tribometer was used through the pin-on-disk method (POD). The used parameters were: load of 10 N, linear speed of 15 $cm \cdot s^{-1}$, motor speed of 475.91 rpm, distance of 750 m, working radius of 3.01 mm, temperature of 20°C and humidity of 50% (like environmental conditions). As a counter body, a steel 100Cr6 ball with a diameter of 6 mm was used. The distance of 750 m meant $39.6 \cdot 10^4$ laps respectively a time of 83 minutes.

The microhardness messurements was carried out with a ZWICK-ROELL apparatus using Vickers method [44]. A 0.3 kgf indentation force was maintained during 15 seconds. The hardness value was calculate as a average of the 5 indentations.

The corrosion resistance was achieved by potentiodynamic polarization by means of a PGP 21 potentiostat/galvanostat in a three electrode electrochemical cell, using the calomel saturated electrode as the reference electrode. The counter electrode was a platinum disc with the surface 1cm^2, and the X20Cr13 sample in 3.5% neutral NaCl solution as the working electrode.

Mechanical properties and chemical composition of X20Cr13 steel are presented in Table 3 and Table 4.

Table 1. Mechanical properties.

Tensile strength, Rm (N·mm^{-2})	Yield strength, Rp 0.2 (N·mm^{-2})	Elongation at yield, A (%)	Elongation at break, Z (%)
853	662	17	62.8

Table 2. Chemical composition (wt.%).

C	Si	Mn	P	S	N	Cr	Mo	Ni	Cu	Fe
0.21	0.32	0.42	0.02	0.025	0.03	12.7	0.06	0.28	0.06	85.87

3. Results and discussion

3.1. Cavitation erosion

Table 3 present the obtained results regarding the cavitation erosion behavior of the X20Cr13 steel and figure 1 and figure 2 present the graphs of cumulative mass loss and cavitation erosion rate versus time curves.

Table 3. Obtained cavitation erosion results.

Cumulated time	Period	Sample mass	Mass loss		Cavitation rate	Cumulated time	Period	Sample mass	Mass loss		Cavitation rate
			On period	Cumulative					On period	Cumulative	
t (min)	Δt (min)	m (mg)	Δm (mg)	mc (mg)	v_{ec} (mg·h^{-1})	t (min)	Δt (min)	m (mg)	Δm (mg)	mc (mg)	v_{ec} (mg·h^{-1})
0	0	15913.29	0	0	0.000	480	30	15862.05	3.31	51.24	6.560
30	30	15910.92	2.37	2.37	5.380	510	30	15858.8	3.25	54.49	6.310
60	30	15907.91	3.01	5.38	6.430	540	30	15855.74	3.06	57.55	6.160
90	30	15904.49	3.42	8.8	6.450	570	30	15852.64	3.1	60.65	6.120
120	30	15901.46	3.03	11.83	6.440	600	30	15849.62	3.02	63.67	6.130
150	30	15898.05	3.41	15.24	6.540	630	30	15846.51	3.11	66.78	6.240
180	30	15894.92	3.13	18.37	6.600	660	30	15843.38	3.13	69.91	6.280
210	30	15891.45	3.47	21.84	6.800	690	30	15840.23	3.15	73.06	6.670
240	30	15888.12	3.33	25.17	6.600	720	30	15836.71	3.52	76.58	7.140
270	30	15884.85	3.27	28.44	6.340	750	30	15833.09	3.62	80.2	6.970
300	30	15881.78	3.07	31.51	6.180	780	30	15829.74	3.35	83.55	6.750
330	30	15878.67	3.11	34.62	6.250	810	30	15826.34	3.4	86.95	6.620
360	30	15875.53	3.14	37.76	6.430	840	30	15823.12	3.22	90.17	6.370
390	30	15872.24	3.29	41.05	6.650	870	30	15819.97	3.15	93.32	6.530
420	30	15868.88	3.36	44.41	6.880	900	30	15816.59	3.38	96.7	6.990
450	30	15865.36	3.52	47.93	6.830	-	-	-	-	-	-

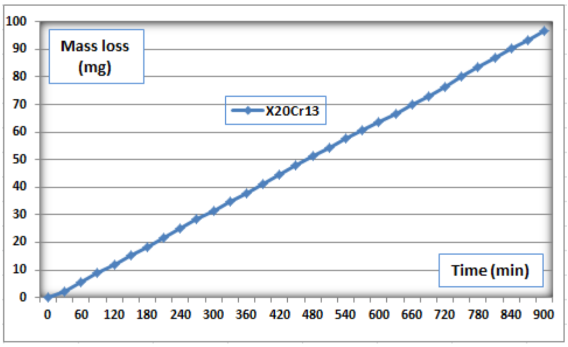


Figure 1. Cumulative mass loss vs time.

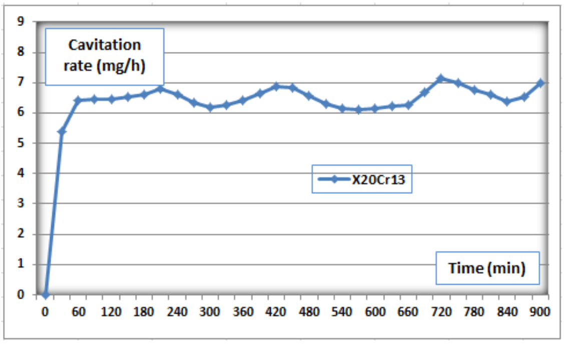


Figure 2. Cavitation erosion rate vs time.

It is observed that the mass loss process occurs linearly with an average of 3.2 mg on a period. The total mass loss was 96.7 mg, value which classifies the X20Cr13 martensitic stainless steel as having a good cavitation erosion resistance [45].

The cavitation erosion rate cross the incubation and acceleration stage for the first 60 minutes of the test and then it is maintain at the maximum rate stage [46] between the range 6 - 7 mg·h^{-1} until the end of the test.

3.2. *Dry sliding wear*

Evolution of friction coefficient is presented in figure 3 and as results in table 4. The measured values for wear rate, volume loss, width and depth of sample wear track are presented in table 5.

Some images regarding the wear track profiles are shown in figure 4.

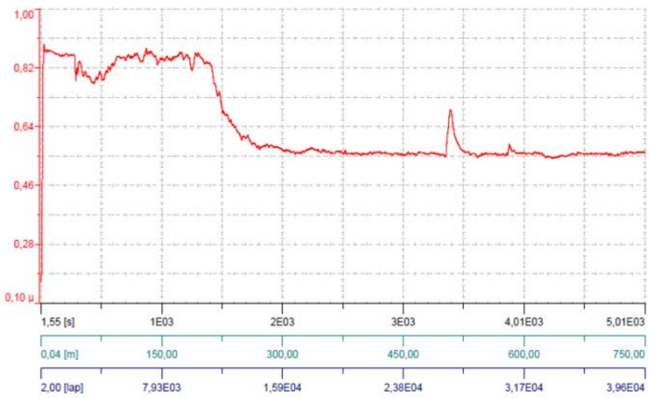


Figure 3. Evolution of friction coefficient.

The coefficient of friction evolution was starting at the 0.165 value (table 4) and was rapidly increasing until to the aprox. 0.96 value. Than vary with a decreasing trend for a distance of 75 m with the 0.82 - 0.96 value range (figure 3).

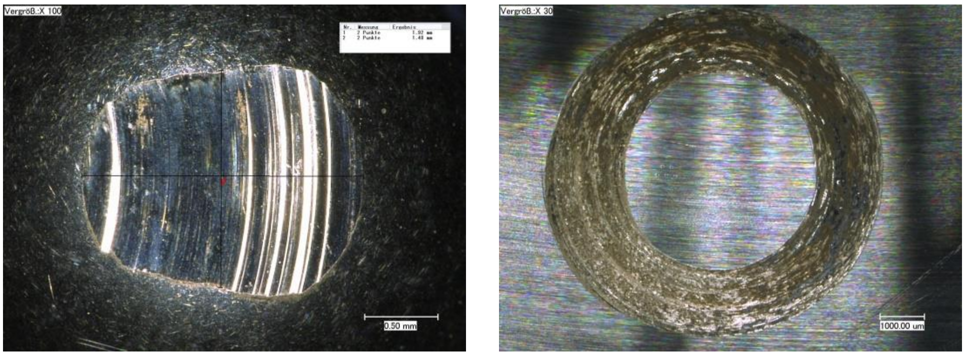
At the aprox. 225 m decreases for the next 75 m around 0.55 and is maintained around this value until around 525 m. Also, from figure 3, it can be seen that the coefficient of friction value increases suddenly to a value of 0.70, but immediately returns to the same level of 0.55 to the final distance of 750 m. For the value of 0.70, it was considered that during the test, eroded material was deposit between the ball and the sample.

Table 4. Friction coefficient results.

Start	Min	Max	Mean	Std. Dev.
0.165	0.165	0.891	0.646	0.128

Table 5. Measured values for wear rate, volume loss, width and depth of sample wear track.

Wear track depth, ***h*** (μm)	Wear track width, ***s*** (μm)	Volume loss, ***V*** (mm^3)	Wear rate, ***K*** ($mm^3N^{-1}m^{-1}$)
52.650	1397.542	0.9256	$1.23 \cdot 10^{-4}$



a) ball wear track *b)sample wear track*

Figure 4. Wear track profiles details.

Regarding the wear track profiles acquired with a digital microscope and with a confocal 3D laser scanning microscope, the length and the width of the ball wear was 1.92 mm respectively 1.48 mm.

3.3. Microhardness

The microhardness values (HV0.3) are presented in table 6 and in figure 5.

Table 6. Microhardness values (HV0.3).

Attempt 1	Attempt 2	Attempt 3	Attempt 4	Attempt 5	Mean value
267	261	245	252	249	255

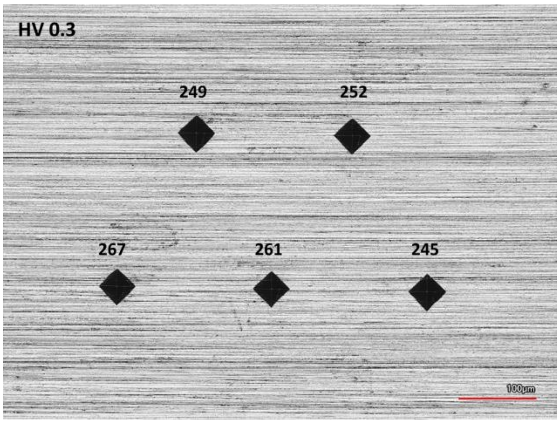


Figure 5. Micrographs of micro-hardness values.

The mean value of the microhardness is 255 HV0.3 and between the 5 indentations are small differences. The obtained values are characteristic for the martensitic stainless steels hardness [47].

3.4. Electrochemical corrosion

The obtained electrochemical corrosion values was determined by Tafel slope method. The logarithm representation of corrosion curve is shown in figure 6.

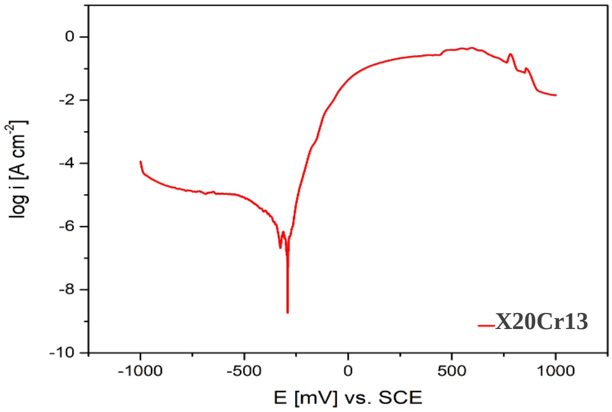


Figure 6. Logarithm representation of X20Cr13 corrosion curve.

From the logarithm representation of corrosion curve, it can be see a passivation tendency around 250 mV and that the anodic branch has a lower current densities. The current density and the potential indicate a lower reaction rate and a good / moderate corrosion resistance of X20Cr13 steel [48].

3.5. Examination of sample surfaces after tests

For the tests regarding the cavitation erosion, dry sliding wear and corrosion, figure 7 show some images with sample surfaces after this tests.

a) cavitation erosion *b) dry sliding wear* *c) corrosion*

Figure 7. Images of wear and corrosion of the sample surfaces after the tests.

It can be seen from the figure 7 that the sample surfaces showed crakes and shallow erosions generated by cavitation erosion over the entire surface; sever wear in the case of dry sliding wear test respectively an intense material destruction in the electrochemical corrosion test.

4. Conclusions

This paper has referred to the cavitation erosion that destroy rotor blades of hydraulic turbines and also to the sliding wear and corrosion that makes damege of the material surface respectively presented the experimental procedure, working parameters and the obtained results for the cavitation erosion, dry sliding wear, microhardness and corrosion of the X20Cr13 steel behaviour.

From the experimental results, it can be highlighted that the analyzed X20Cr13 steel, like a martensitic stainless steel, shown a good cavitation erosion resistance (due to chromium content), a low dry sliding wear resistance (as the coefficient of friction and wear rate results show) respectively a good / moderate corrosion resistance (that because the higher Cr content, which is favoring an easier passivation), all this compared to other materials investigated from the authors.

Regarding the Vickers microhardness obtained results, these are reliable and typical for this martensitic stainless steel.

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