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Cavitation Erosion Tests Performed by Indirect Vibratory Method on Stainless Steel Welded Samples with Hardened Surface

The paper presents the results of cavitation erosion tests performed on two types of samples. The materials of the samples are frequently used for manufacturing and repairs of the hydro turbines components submitted to cavitation. The first sample was made by welding of an austenitic stainless steel on austenito-feritic base material. The second sample was made similarly with the first but with a martensitic base material. After the welding processes, on both samples was applied a hardening treatment by surface peening. The cavitation erosion tests were performed on vibratory equipment using the indirect method with stationary specimen. The results show a good cavitation erosion resistance on both samples.

Keywords: *cavitation erosion, peening, vibratory method, stationary specimen, stainless steel*

1. Introduction

In order to study the cavitation erosion resistance of the welded overlays from the blades of the Kaplan hydroturbines submitted to cavitation, samples who simulate the in-situ repairs were used [1,2]. The samples were made by welding of an austenitic stainless steel, with good cavitation resistance, on two types of base materials: an austenito-feritic stainless steel, 1.4571 (X6CrNiMoTi17-12-2, EN 10088-2) and a martensitic stainless steel, 1.4313 (X3CrNiMo13-4, EN 10088-2). The total thickness of the welded overlays was 7 mm for the both samples (table 1). After the welding processes, on both samples was applied a hardening treatment by surface peening. Table 2 shows the chemical composition of the base materials in accordance with test certificates provided by the manufacturer and table 3 shows the chemical composition of the filler material provided by the manufacturer [1,2].

Table 1.

Sample	Basic material	Filler material	Deposited method	Welded layers thickness
Sample 1	austenitic-feritic stainless steel 1.4571	austenitic stainless steel	welding overlays	7 mm
Sample 2	martensitic stainless steel 1.4313	austenitic stainless steel	welding overlays	7 mm

Table 2.

Chemical composition [%] of austenito-feritic stainless steel 1.4571									
C	Cr	Mn	Mo	N	Ni	P	S	Si	Ti
0,033	16,78	1,606	2,073	0,015	11,21	0,025	0,001	0,463	0,303
Chemical composition [%] of martensitic stainless steel 1.4313									
C	Cr	Mn	Mo	N	Ni	P	S	Si	Ti
0,050	12,93	1,500	0,490	0,510	3,690	0,040	0,015	0,700	0,012

Table 3.

Chemical composition [%] of filler material									
C	Si	Mn	Cr	Ni	Mo	Co	S	P	Fe
0,246	2,24	10,15	16,24	0,5	0,39	12,37	0,003	0,015	bal

The mechanical properties of the base materials are presented in table 4. For the filler material the producers indicates only the hardness (aprox. 240HB).

Table 4.

The mechanical characteristics of stainless steel 1.4571 austenitic-ferritic (X6CrNiMoTi17-12-2) and 1.4313 martensitic stainless steel (X3CrNiMo13-4)						
Material	Rm	Rp 0.2	Rp 1.0	A50	A5	Hardness
	[N/mm2]	[N/mm2]	[N/mm2]	[%]	[%]	
1.4571	559.67	310.71	344.38	53.85	52.85	90 HRB
1.4313	760	630	-	-	15	<285 HB

2. Vibratory cavitation method with stationary specimen

Cavitation erosion test in the laboratory conditions can be made using three methods: vibratory method (or ultrasonic method), cavitating liquid jet method and Venturi cavitation method. The vibratory method is the most used due the simplicity of the testing procedure and due to the testing time, relatively short. This method uses a piezoelectric device or a magnetostrictive device to produce a high-

frequency vibration. This vibration is transmitted by a booster (mechanical transformer of vibration) and a sonotrode to a test specimen immersed in liquid. The method is standardized by ASTM G-32 norm [3].

The equipment used for the cavitation tests in the Center for Research in Hydraulics, Automation and Thermal Processes of „Eftimie Murgu" University of Reşiţa is an ultrasonic equipment with piezoelectrical converter. The unit consists of the following components [4]: a) ultrasonic generator and b) cavitation stand with piezelectrical converter, booster, sonostrode and cooling bath.

On the materials used in this reaserch were initially made cavitation erosion tests by the direct vibratory method [1,2]. On the direct method, the vibratory device generates oscillations on a test specimen attached at the sonotrode (by a thread) and submerged in liquid at a certain depth (figure 1).

Due to the high cavitation resistance of the materials used in the repairs of hidroturbines components, the period of testing for these types of materials is large. The thread of sonotode and the thread of sample are submitted to fatigue. Due these aspects the lifetime of sonotrode, at the direct method of testing, is limited. In order to increase the lifetime of sonotrode and in order to simplify the samples (test specimens) manufacturing, the indirect vibratory method can be use.

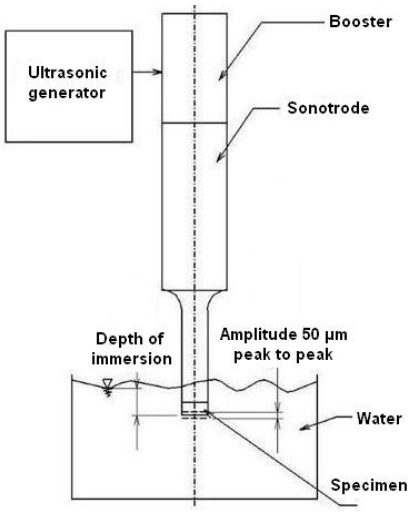


Figure 1. The principle of the direct cavitation method [4]

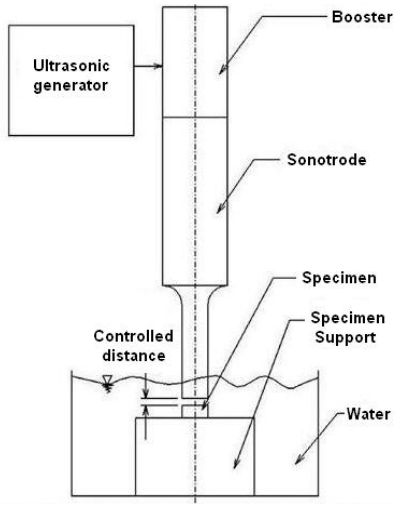


Figure 2. The principle of the indirect cavitation method [5]

At the indirect method (or stationary specimen method) [figure 2], the specimen is fixed (not attached to the sonotrode) and fully immersed in the liquid. The sonotrode vibrate at a certain distance above the specimen (usually 0.5-0.7 mm) and is also partially immersed in liquid.

3. Results of the cavitation erosion research on sample 1

The cavitation erosion tests were performed using the vibratory method with stationary specimen. The frequency of oscillation was f=20 ± 0.5 kHz and the amplitude A=45 μm. The water temperature was maintained at 25 ± 2 degrees using a cooling system with water from the Resita water supply system. The distance between the sample and the sonotrode was 0.7mm.

Table 5 presents the tests results for the sample 1 (austenitic stainless steel welded on martensitic stainless steel) for 1320 minutes of cavitational attack.

Table 5. Results of cavitation erosion tests on sample 1

Total time	Phase time	Specimen Mass	Eroded Mass		Erosion rate/phase	Cumulative erosion rate
			phase	cumulative		
t [min]	Δt [min]	m [mg]	Δm [mg]	Δmc [mg]	vef [mg/min]	vec [mg/min]
0	0	15126.290	0.0000	0.0000	0.0000	0.0000
7	7	15126.240	0.0500	0.0500	0.0071	0.0071
22	15	15126.170	0.0700	0.1200	0.0047	0.0080
37	15	15126.130	0.0400	0.1600	0.0027	0.0107
52	15	15126.110	0.0200	0.1800	0.0013	0.0120
67	15	15126.090	0.0200	0.2000	0.0013	0.0133
82	15	15126.080	0.0100	0.2100	0.0007	0.0140
97	15	15126.070	0.0100	0.2200	0.0007	0.0147
112	15	15126.060	0.0100	0.2300	0.0007	0.0153
127	15	15126.050	0.0100	0.2400	0.0007	0.0160
142	15	15126.040	0.0100	0.2500	0.0007	0.0167
157	15	15126.030	0.0100	0.2600	0.0007	0.0173
172	15	15126.030	0.0000	0.2600	0.0000	0.0173
187	15	15126.020	0.0100	0.2700	0.0007	0.0180
202	15	15126.010	0.0100	0.2800	0.0007	0.0187
217	15	15126.000	0.0100	0.2900	0.0007	0.0193
232	15	15125.990	0.0100	0.3000	0.0007	0.0200
247	15	15125.980	0.0100	0.3100	0.0007	0.0207
277	30	15125.970	0.0100	0.3200	0.0003	0.0107
307	30	15125.950	0.0200	0.3400	0.0007	0.0113
337	30	15125.930	0.0200	0.3600	0.0007	0.0120
367	30	15125.910	0.0200	0.3800	0.0007	0.0127
397	30	15125.900	0.0100	0.3900	0.0003	0.0130
427	30	15125.890	0.0100	0.4000	0.0003	0.0133
457	30	15125.880	0.0100	0.4100	0.0003	0.0137

Table 5 (continued from previous page)

487	30	15125.870	0.0100	0.4200	0.0003	0.0140
517	30	15125.860	0.0100	0.4300	0.0003	0.0143
547	30	15125.850	0.0100	0.4400	0.0003	0.0147
577	30	15125.840	0.0100	0.4500	0.0003	0.0150
607	30	15125.830	0.0100	0.4600	0.0003	0.0153
652	45	15125.780	0.0500	0.5100	0.0011	0.0113
697	45	15125.740	0.0400	0.5500	0.0009	0.0122
742	45	15125.630	0.1100	0.6600	0.0024	0.0147
787	45	15125.600	0.0300	0.6900	0.0007	0.0153
832	45	15125.520	0.0800	0.7700	0.0018	0.0171
877	45	15125.470	0.0500	0.8200	0.0011	0.0182
922	45	15125.430	0.0400	0.8600	0.0009	0.0191
967	45	15125.320	0.1100	0.9700	0.0024	0.0216
1012	45	15125.210	0.1100	1.0800	0.0024	0.0240
1057	45	15125.160	0.0500	1.1300	0.0011	0.0251
1102	45	15125.100	0.0600	1.1900	0.0013	0.0264
1147	45	15125.050	0.0500	1.2400	0.0011	0.0276
1192	45	15124.960	0.0900	1.3300	0.0020	0.0296
1237	45	15124.850	0.1100	1.4400	0.0024	0.0320
1282	45	15124.790	0.0600	1.5000	0.0013	0.0333
1327	45	15124.740	0.0500	1.5500	0.0011	0.0344

Figure 3 shows the graph of cumulative eroded mass variation at sample 1.

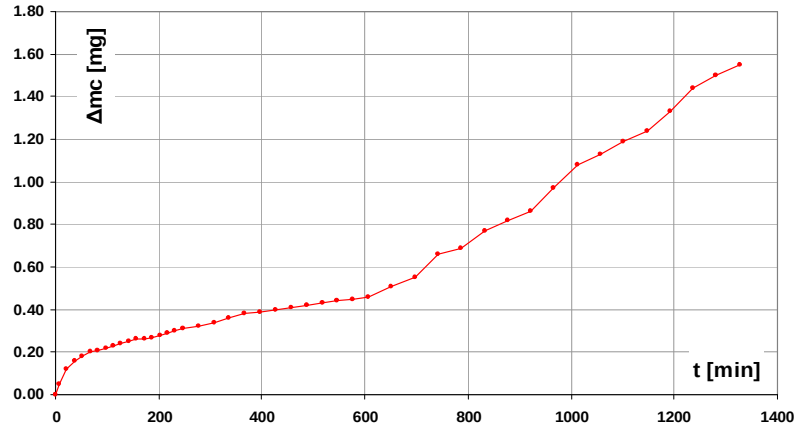


Figure 3. Cumulative eroded mass variation. Sample 1

The graphs of erosion rate (phase and cumulative time) for sample 1 are shown in figures 4 and 5. Figure 6 shows pictures of active surface of sample 1 after cavitation erosion tests. Figure 7 shows details of the active surface macro-structures obtained with an optical microscope at a magnification scale of 50x.

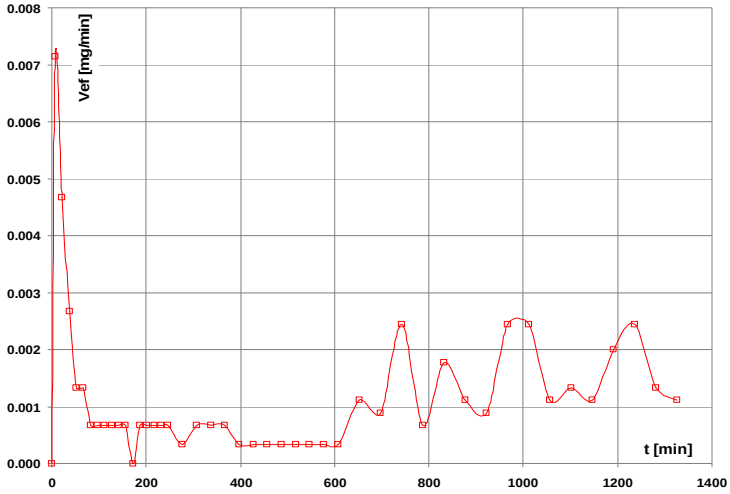


Figure 4. Variation of erosion rate/phase versus time. Sample 1

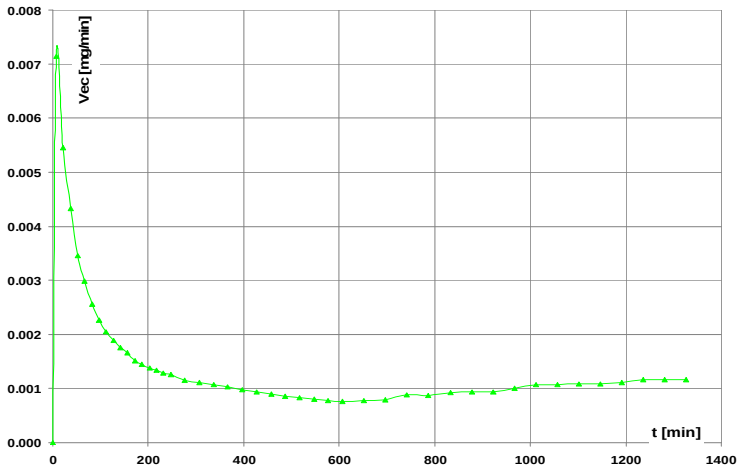
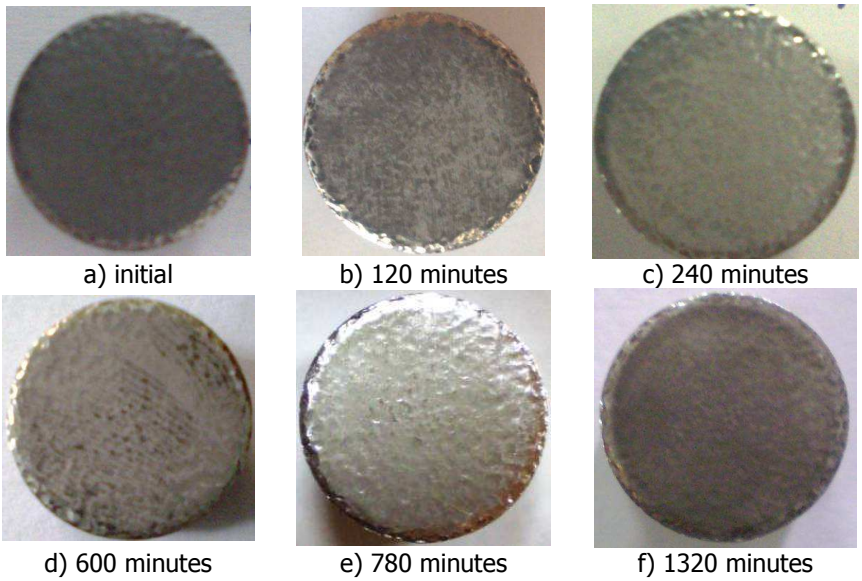


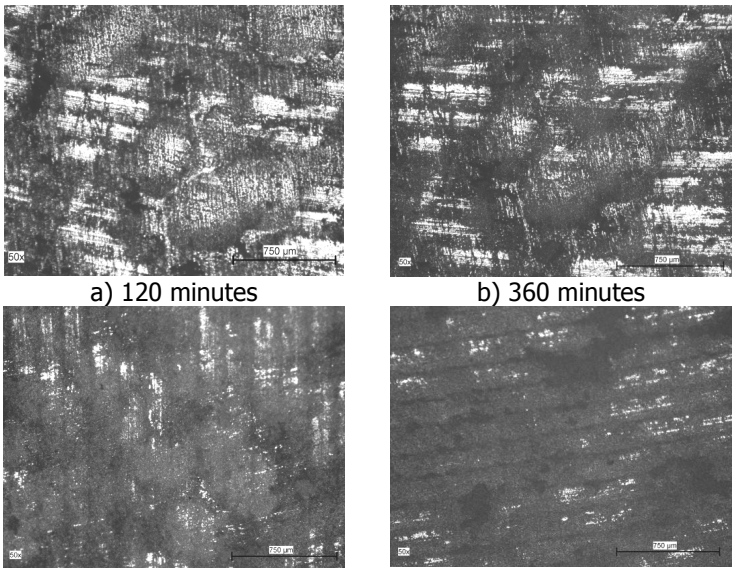
Figure 5. Variation of cumulative erosion rate versus time. Sample 1



a) initial b) 120 minutes c) 240 minutes

d) 600 minutes e) 780 minutes f) 1320 minutes

Figure 6. Surface of sample 1, initial (a) and after cavitation erosion (b-f)



a) 120 minutes b) 360 minutes

c) 780 minutes d) 1320 minutes

Figure 7. Macrostructure of eroded surface of sample 1

4. Results of the cavitation erosion research on sample 2

The sample 2 was tested at the same conditions with the sample 1. The total testing time was only 120 minutes. The results are presented in table 6. Figure 8 shows the graph of cumulative eroded mass variation.

Table 6. Results of cavitation erosion tests on sample 2

Total time	Phase time	Specimen Mass	Eroded Mass		Erosion rate/phase	Cumulative erosion rate
			phase	cumulative		
t [min]	Δt [min]	m [mg]	Δm [mg]	Δmc [mg]	vef [mg/min]	vec [mg/min]
0	0	15212.230	0.00000	0.00000	0.00000	0.00000
5	5	15212.170	0.06000	0.06000	0.01200	0.0120
15	10	15212.020	0.15000	0.21000	0.01500	0.0140
30	15	15211.860	0.16000	0.37000	0.01067	0.012333
45	15	15211.850	0.01000	0.38000	0.00067	0.008444
60	15	15211.830	0.02000	0.40000	0.00133	0.006667
75	15	15211.790	0.04000	0.44000	0.00267	0.005867
90	15	15211.770	0.02000	0.46000	0.00133	0.005111
105	15	15211.760	0.01000	0.47000	0.00067	0.004476
120	15	15211.730	0.03000	0.50000	0.00200	0.004167

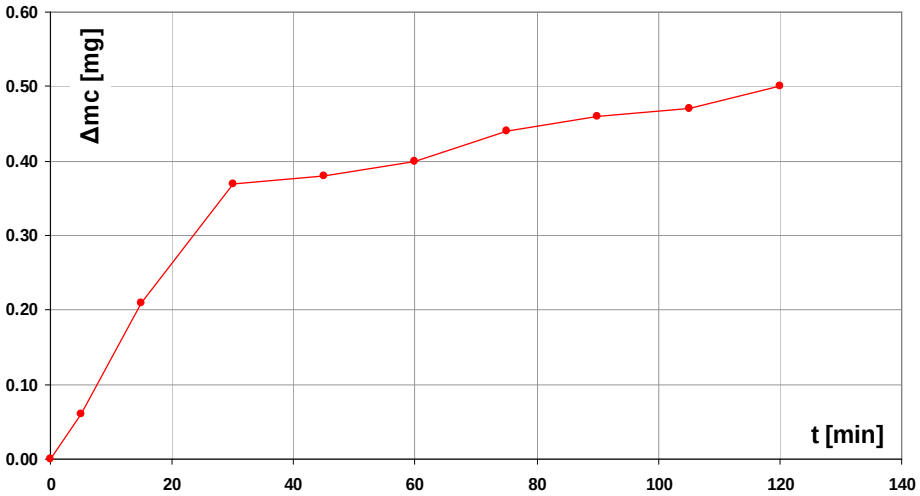


Figure 8. Cumulative eroded mass variation. Sample 2

The graphs of erosion rate (phase and cumulative time) for sample 2 are shown in figures 9 and 10. Figure 11 shows pictures of active surface of sample 2 after cavitation erosion tests. Figure 12 shows details of the active surface macro-structures obtained with an optical microscope at a magnification scale of 50x.

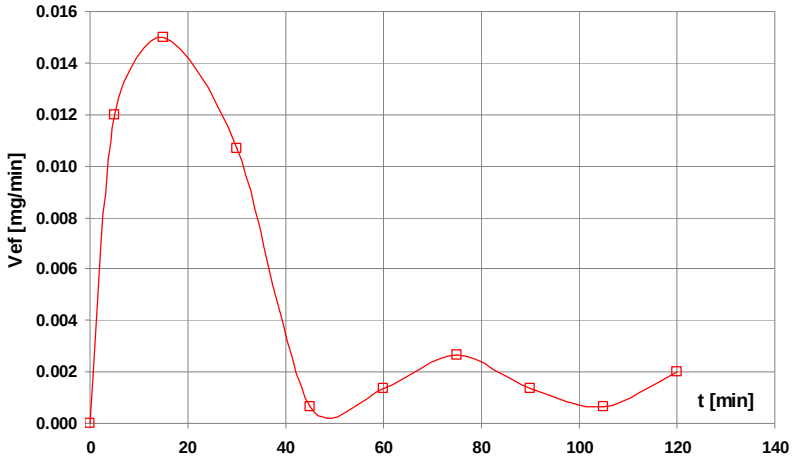


Figure 9. Variation of erosion rate/phase versus time. Sample 2

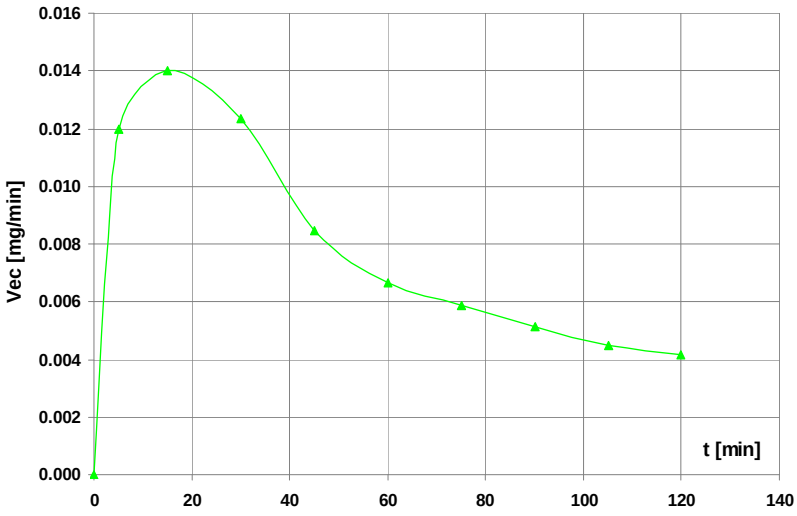
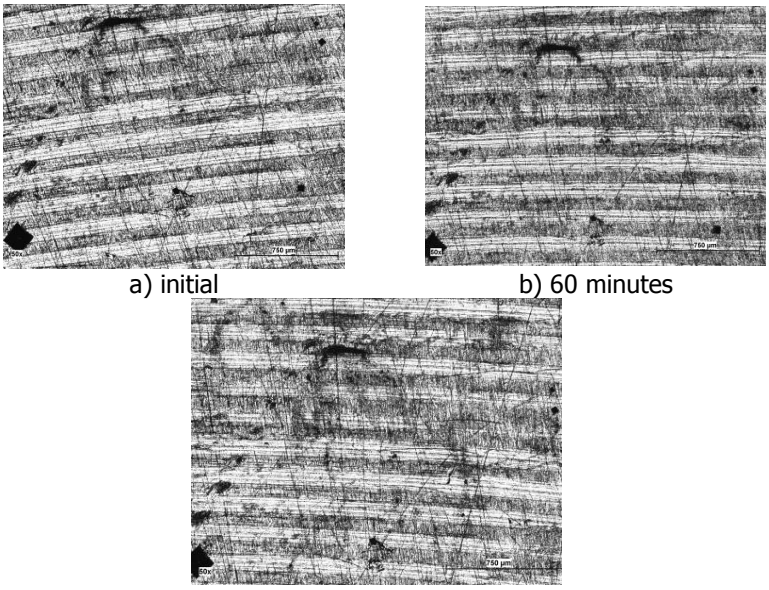


Figure 10. Variation of cumulative erosion rate versus time. Sample 2

a) initial b) 60 minutes c) 120 minutes

Figure 11. Surface of sample 2, initial (a) and after cavitation erosion (b,c)



a) initial b) 60 minutes

c) 120 minutes

Figure 12. Macrostructure of eroded surface of sample 2

Comparing the two samples in terms of total mass eroded (Figure 13) can be seen that the total mass loss at 120 minutes is higher for sample 2 (austenitic stainless steel welded on a martensitic base material).

Analyzing the results related to the data of the literature [5], [7], [8], [9] the two types of samples tested have a high resistance at cavitation erosion.

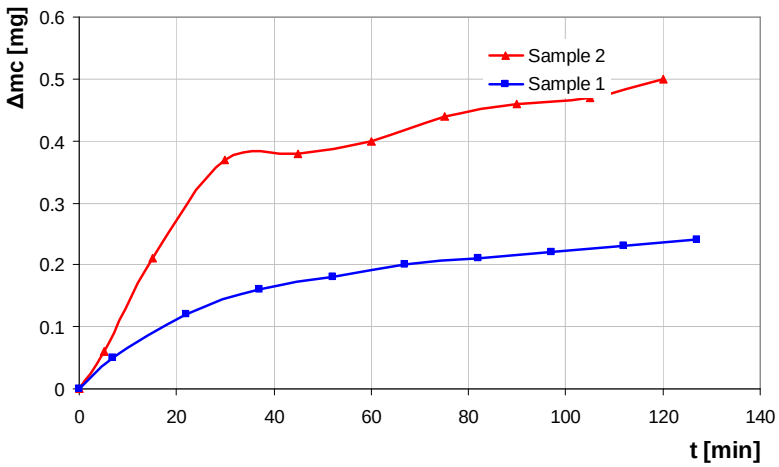


Figure 13. Comparison of cumulative eroded mass variation

5. Conclusion

The cavitation erosion tests made by indirect vibratory method on two welded samples of austenitic stainless steel with a austenito-feritic stainless steel base material (sample 1) and a martensitic stainless steel (sample 2) base materials stainless steel shows that these materials have a high resistance to cavitation erosion.

The higher erosion resistance is obtained for the sample 1. After 1320 minutes of testing the total eroded mass is about 1.60 mg.

The analyses of the surfaces submitted to cavitation don't show significant transformations of the surface.

According to data from the literature [6] by the loss of material in the vibratory devices using indirect set-up (stationary specimen) is lower than at the direct set-up (specimen fixed on sonotrode).

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