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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

Marian-Dumitru Nedeloni, Eugen Birtărescu, Lidia Nedeloni, Aurel Băra, Adrian Pellac

*This paper presents some information regarding the hydraulic turbines respectively the experimental results on cavitation erosion behavior of a 13Cr-4Ni stainless steel used to manufacture the components exposed to water of the Francis, Kaplan and Pelton hydraulic turbines. So, the presented experimental results of this paper highlight the good cavitation erosion resistance of the analyzed 13Cr-4Ni stainless steel.*

***Keywords**: good cavitation erosion resistance, 13Cr-4Ni stainless steel, hydraulic turbines*

## 1. Introduction

The cavitation phenomenon means the formation of the cavitation bubbles [1], cavitation bubbles that occurs in hydraulic machines such as hydraulic turbines especially in their components like runners and blades runner [2] – [6].

In time, this cavitation bubbles through the cavitation erosion, destroy the materials of which the runners and blades runner are made [7] – [9].

In many laboratories, different metallic materials are testing to see their resistance against the cavitation erosion [10] – [13].

In this way, many tests are made on the experimental cavitation stands, like vibratory apparatus [14] and [15] especially according with specific standards [16] and [17].

Also, in this present paper, using an experimental cavitation stand, through the indirect cavitation method [18] and [19], a 13Cr-4Ni stainless steel used to manufacture the components exposed to water of the hydraulic turbines was tested, stainless steel which had a good cavitation erosion resistance.

For a 13Cr-4Ni stainless steel (X3CrNi13-4), different results are obtained [20] – [23] of course for different working parameters and for different chemical composition. The chemical composition for this analyzed stainless steel in this paper is shown in Table 1.

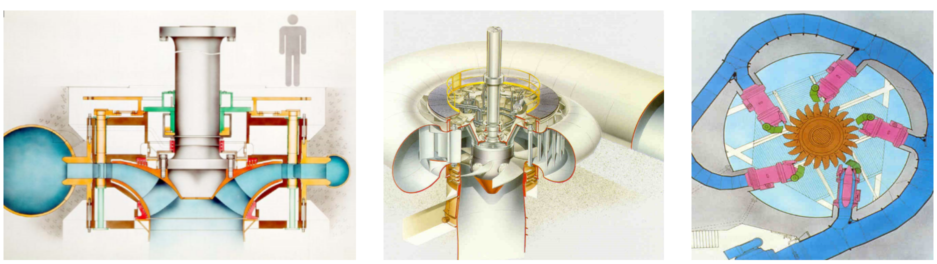
**Table 1.**

| Chemical composition for 13Cr-4Ni stainless steel (X3CrNi13-4) [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| C | Si | Mn | P | S | Cu | Ni | Cr | Mo | Fe |
| 0,055 | 0,62 | 0,65 | 0,021 | 0,012 | 0,25 | 3,62 | 12,95 | 0,36 | 81,46 |

## 2. Hydraulic turbines and their exposed to water components

For the hydraulic turbines manufacturing (Francis, Kaplan and Pelton – Figure 1), the 13Cr-4Ni stainless steel is a very use material for the guide vanes, labyrinth seals, nozzle, runner and blades runner of this types of hydraulic turbines [24].

The components most affected by cavitation erosion are the blades runner of the hydraulic turbines – Figure 2 ([27] and [9]).



*a) Francis* *b) Kaplan* *c) Pelton*

**Figure 1.** The Francis, Kaplan and Pelton hydraulic turbines.

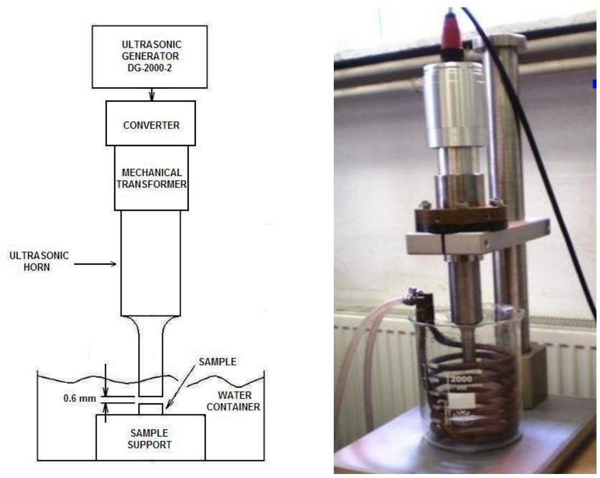
*a) Francis runner* *b) Kaplan runner* *c) Pelton runner*

**Figure 2.** Images of hydraulic turbines runners eroded by cavitation erosion.

### 3. The experimental cavitation stand and experimental results

The experimental cavitation stand (Figure 3), function at the natural frequency of 20 ± 0.5 kHz, in the following working conditions (G32-10 standard [16]):

- amplitude: 50 μm;
- liquid temperature: 25 ± 2 °C;
- distance between the used ultrasonic horn and sample: 0.6 mm.




*a) Sketch [26]* *b) Vibratory apparatus*

**Figure 3.** The experimental cavitation stand.

The samples from the 13Cr-4Ni stainless steel (X3CrNi13-4), were made in cylindrical form (Φ16x10 mm) [27]. For the obtained experimental results (Tables 2 ÷ 6), only a one surface of the 2 samples, has been subjected to cavitation erosion for 180 minutes, so in total 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 | 15030.56 | 0 | 0 | 0.0000 | 0.000 |
| 5 | 5 | 15030.55 | 0.01 | 0.01 | 0.0017 | 0.100 |
| 15 | 10 | 15030.54 | 0.01 | 0.02 | 0.0006 | 0.036 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 30 | 15 | 15030.54 | 0 | 0.02 | 0.0003 | 0.020 |
| 45 | 15 | 15030.53 | 0.01 | 0.03 | 0.0007 | 0.040 |
| 60 | 15 | 15030.52 | 0.01 | 0.04 | 0.0047 | 0.280 |
| 75 | 15 | 15030.39 | 0.13 | 0.17 | 0.0090 | 0.540 |
| 90 | 15 | 15030.25 | 0.14 | 0.31 | 0.0130 | 0.780 |
| 105 | 15 | 15030 | 0.25 | 0.56 | 0.0177 | 1.060 |
| 120 | 15 | 15029.72 | 0.28 | 0.84 | 0.0220 | 1.320 |
| 135 | 15 | 15029.34 | 0.38 | 1.22 | 0.0280 | 1.680 |
| 150 | 15 | 15028.88 | 0.46 | 1.68 | 0.0313 | 1.880 |
| 165 | 15 | 15028.4 | 0.48 | 2.16 | 0.0360 | 2.160 |
| 180 | 15 | 15027.8 | 0.6 | 2.76 | 0.0440 | 2.640 |

**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 | 15027.81 | 0 | 0 | 0.0000 | 0.000 |
| 5 | 5 | 15027.8 | 0.01 | 0.01 | 0.0023 | 0.140 |
| 15 | 10 | 15027.77 | 0.03 | 0.04 | 0.0021 | 0.124 |
| 30 | 15 | 15027.76 | 0.01 | 0.05 | 0.0017 | 0.100 |
| 45 | 15 | 15027.72 | 0.04 | 0.09 | 0.0033 | 0.200 |
| 60 | 15 | 15027.66 | 0.06 | 0.15 | 0.0040 | 0.240 |
| 75 | 15 | 15027.6 | 0.06 | 0.21 | 0.0107 | 0.640 |
| 90 | 15 | 15027.34 | 0.26 | 0.47 | 0.0157 | 0.940 |
| 105 | 15 | 15027.13 | 0.21 | 0.68 | 0.0163 | 0.980 |
| 120 | 15 | 15026.85 | 0.28 | 0.96 | 0.0210 | 1.260 |
| 135 | 15 | 15026.5 | 0.35 | 1.31 | 0.0260 | 1.560 |
| 150 | 15 | 15026.07 | 0.43 | 1.74 | 0.0323 | 1.940 |
| 165 | 15 | 15025.53 | 0.54 | 2.28 | 0.0347 | 2.080 |
| 180 | 15 | 15025.03 | 0.5 | 2.78 | 0.0320 | 1.920 |

**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 | 15273.14 | 0 | 0 | 0.0000 | 0.000 |
| 5 | 5 | 15273.1 | 0.04 | 0.04 | 0.0057 | 0.340 |
| 15 | 10 | 15273.09 | 0.01 | 0.05 | 0.0027 | 0.164 |
| 30 | 15 | 15273.01 | 0.08 | 0.13 | 0.0033 | 0.200 |
| 45 | 15 | 15272.99 | 0.02 | 0.15 | 0.0033 | 0.200 |
| 60 | 15 | 15272.91 | 0.08 | 0.23 | 0.0040 | 0.240 |
| 75 | 15 | 15272.87 | 0.04 | 0.27 | 0.0077 | 0.460 |
| 90 | 15 | 15272.68 | 0.19 | 0.46 | 0.0130 | 0.780 |
| 105 | 15 | 15272.48 | 0.2 | 0.66 | 0.0173 | 1.040 |
| 120 | 15 | 15272.16 | 0.32 | 0.98 | 0.0203 | 1.220 |
| 135 | 15 | 15271.87 | 0.29 | 1.27 | 0.0227 | 1.360 |
| 150 | 15 | 15271.48 | 0.39 | 1.66 | 0.0283 | 1.700 |
| 165 | 15 | 15271.02 | 0.46 | 2.12 | 0.0310 | 1.860 |
| 180 | 15 | 15270.55 | 0.47 | 2.59 | 0.0317 | 1.900 |

**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 | 15270.56 | 0 | 0 | 0.0000 | 0.000 |
| 5 | 5 | 15270.55 | 0.01 | 0.01 | 0.0017 | 0.100 |
| 15 | 10 | 15270.54 | 0.01 | 0.02 | 0.0006 | 0.036 |
| 30 | 15 | 15270.54 | 0 | 0.02 | 0.0003 | 0.020 |
| 45 | 15 | 15270.53 | 0.01 | 0.03 | 0.0037 | 0.220 |
| 60 | 15 | 15270.43 | 0.1 | 0.13 | 0.0073 | 0.440 |
| 75 | 15 | 15270.31 | 0.12 | 0.25 | 0.0093 | 0.560 |
| 90 | 15 | 15270.15 | 0.16 | 0.41 | 0.0103 | 0.620 |
| 105 | 15 | 15270 | 0.15 | 0.56 | 0.0137 | 0.820 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 120 | 15 | 15269.74 | 0.26 | 0.82 | 0.0173 | 1.040 |
| 135 | 15 | 15269.48 | 0.26 | 1.08 | 0.0233 | 1.400 |
| 150 | 15 | 15269.04 | 0.44 | 1.52 | 0.0317 | 1.900 |
| 165 | 15 | 15268.53 | 0.51 | 2.03 | 0.0343 | 2.060 |
| 180 | 15 | 15268.01 | 0.52 | 2.55 | 0.0350 | 2.100 |

**Table 6.**

| Cumulated time | Cumulated Eroded mass | Cavitation erosion rate |
|---|---|---|
| t | $m_c$ | $v_e$ |
| [min] | [mg] | [mg/h] |
| 0 | 0.0 | 0.0 |
| 5 | 0.0 | 0.2 |
| 15 | 0.0 | 0.1 |
| 30 | 0.1 | 0.1 |
| 45 | 0.1 | 0.2 |
| 60 | 0.1 | 0.3 |
| 75 | 0.2 | 0.6 |
| 90 | 0.4 | 0.8 |
| 105 | 0.6 | 1.0 |
| 120 | 0.9 | 1.2 |
| 135 | 1.2 | 1.5 |
| 150 | 1.6 | 1.9 |
| 165 | 2.1 | 2.0 |
| 180 | 2.7 | 2.1 |

After the obtained results, the mass loss curves (Figures 4 and 6) and cavitation erosion rate vs time curves (Figures 5 and 7), were made. So, sides 1 and 2 of the sample 1 lost a weight, each of 2.76 [mg] respectively 2.78 [mg] and the sides 1 and 2 of the sample 2 lost a weight each of 2.59 [mg] respectively 2.55 [mg].

The images of the samples before and after the cavitation are shown in Figures 8 ÷ 11.

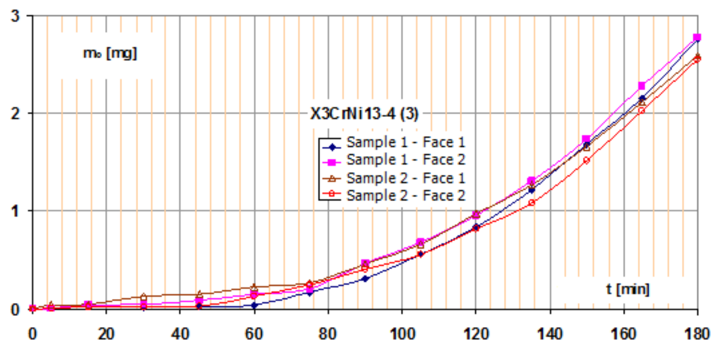



**Figure 4.** The material loss curves.

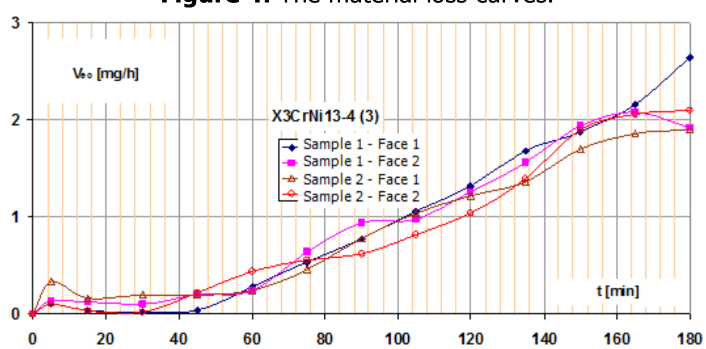



**Figure 5.** The cavitation erosion rate vs time curves.

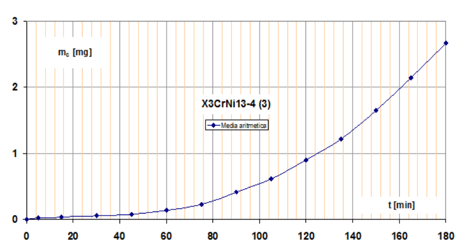



**Figure 6.** The material loss curve.

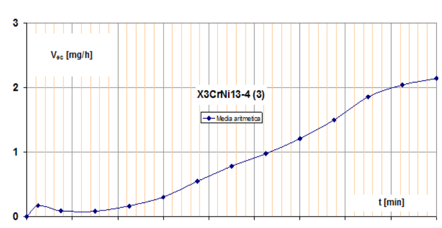



**Figure 7.** The cavitation erosion rate curve.

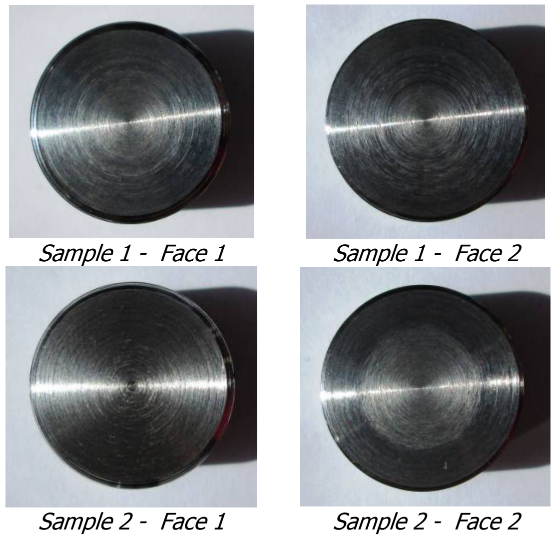



**Figure 8.** Images of samples before the cavitation erosion.

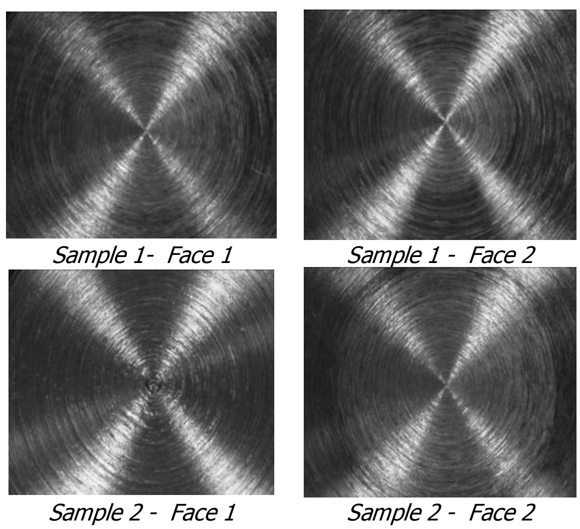



**Figure 9.** Macrostructures of samples before the cavitation erosion.

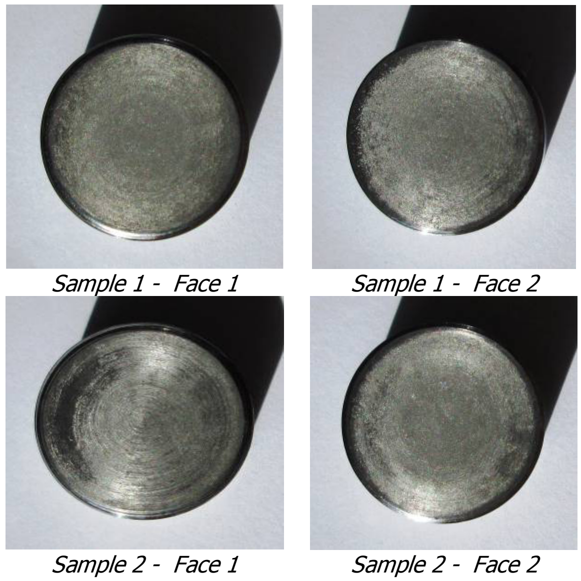



**Figure 10.** Images of samples after the cavitation erosion (180 minutes).

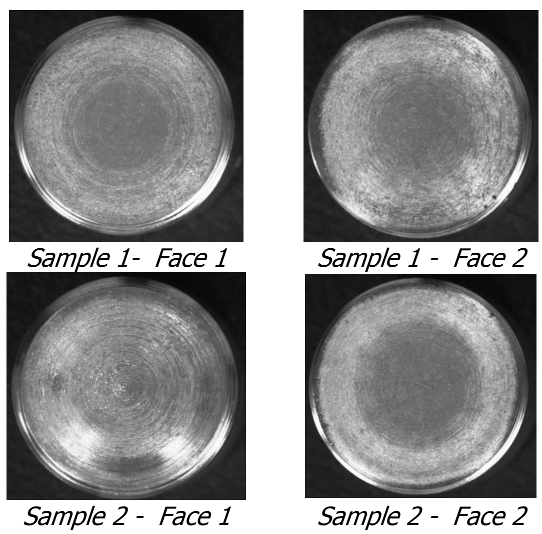



**Figure 11.** Macrostructures of samples after the cavitation erosion (180 minutes).

## 4. Conclusion

Of the four tested surfaces, the most resistance against cavitation erosion was surface 2 of sample 2 (2.55 [mg]), and the lowest cavitation erosion was surface 2 of sample 1 (2.78 [mg]);

Regarding the greatest value of the mass lost for a testing standard period (15 minutes) of this four tested surfaces, this was: 0.6 [mg] for *Sample 1 - Face 1*; 0.54 [mg] for *Sample 1 - Face 2*; 0.47 [mg] for *Sample 2 - Face 1* and 0.52 [mg] for *Sample 2 - Face 2*;

Comparing with other obtained results from other references in this paper, the analyzed 13Cr-4Ni stainless steel, show a good cavitation erosion resistance.

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*Addresses:*


- Asist. PhD. Eng. Marian-Dumitru Nedeloni, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, m.nedeloni@uem.ro
- PhD. stud. Eng. Eugen Birtărescu, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, e.birtarescu@uem.ro
- PhD. stud. Eng. Lidia Nedeloni, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, l.filip@uem.ro
- PhD. stud. Eng. Aurel Băra, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, abara@resitareductoare.com
- PhD. stud. Eng. Adrian Pellac, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, adi80pellac@yahoo.com