Cavitation Erosion and Dry Sliding Wear Research on X5CrNi18-10 Austenitic Stainless Steel

M D Nedeloni, E Birtărescu*, L Nedeloni, T Ene, A Băra and B Clavac

Eftimie Murgu University of Reșița, Faculty of Engineering and Management, Piața Traian Vuia, No. 1-4, 320085, Reșița, Romania

*Corresponding author: e.birtarescu@uem.ro

Abstract. In this research, the cavitation erosion and dry sliding wear behavior of X5CrNi18-10 austenitic stainless steel has been analyzed through many tests. Cavitation erosion tests have been made for 180 minutes for the two samples and then for an extended duration of 1800 minutes for the surface which exhibited the best behaviour. All this tests were made using a cavitation experimental stand with the following main parameters for the ultrasonic generator (frequency: 20 ±0.5 kHz and amplitude: 50 μm). Dry sliding wear test has been made using a tribometer with the parameters: applied force 10 N, line speed 15 cm/s and distance 750 m. The analysed X5CrNi18-10 austenitic stainless steel had showed very good cavitation erosion behaviour, but a low dry sliding wear resistance compared to other steels as can be seen in the obtained results presented as cumulative mass loss and cavitation erosion rate for the cavitation erosion tests and as coefficient of friction and wear rate for the dry sliding wear test.

1. Introduction

Electricity production by classical methods is obtained in power plants, where a major category is the hydro power plant, of which the hydraulic turbines are part [1]. For the manufacture the hydraulic turbine components, steel, cast iron, bronze as metallic materials and certain small quantities of non-metallic materials can be used [2,3]. Most components are manufactured of different types of steel, such as carbon, treated and stainless steel [4-6].

The characteristic wear mechanisms that can occur on these components are: abrasive, adhesive and sliding wear respectively erosion, which can be cavitation erosion, hydro-abrasion, sediment and sand erosion. Besides to these different types of wear, other damage can occur due to the working environment or inadequate maintenance such as: typical rotor blocking, inadequate heat treatment or erosion associated with corrosion [1]. From the hydraulic turbine components, the rotor is the most affected by cavitation erosion.

The cavitation erosion occurs as a result of the cavitation phenomenon encountered in the fluid environment where the rotors and the rotor blades operate. The phenomenon of cavitation is described as a dynamic process of forming, developing and blowing up bubbles or cavities filled with vapors and gases in the mass of a liquid [7].

In the process of implosion is an assembly of simultaneous phenomena of mechanical, chemical, electrical and thermal nature [8,9]. Different research on the cavitation erosion of materials respectively on the cavitation phenomenon has been made by several authors with regard to the negative effects of cavitation erosion, to vibrations analysis or to the cavitation vortex [10-13].
It can be said that worldwide, the research purpose through laboratory testing of the cavitation erosion of materials is to discover new materials with good behavior, materials that have high hardness, tear strength, fine grain, homogeneity etc. [14-16]. In general, materials having a high cavitation erosion resistance are of two categories: materials used in the manufacture of hydraulic turbine components and materials used for refurbishing them [17].

In order to test cavitation erosion resistance of materials, there are numerous types of laboratories apparatus such as: cavitation tunnels, vibratory cavitation apparatus and cavitating liquid jets [6]. Of the tested materials with vibratory cavitation apparatus, the less cavitation erosion resistance have Al alloys and the highest is attributed to the Stellite coating followed by stainless steel and Cr-Ni alloys [18-20]. In general, the behavior of these materials (other than Stellite) can be improved by certain treatments [21-26]. In other different technical applications, stainless steels, in particular the X5CrNi18-10 austenitic stainless steel has been tested [27-29].

At the Eftimie Murgu University of Resita the calibration of the cavitation experimental stand (as a vibratory cavitation apparatus) was performed [30,31] and by testing a series of materials, the highest cavitation erosion resistance was attributed to the stainless steel (X5CrNi18-10), then to the treated carbon steels, followed by cast iron, bronze and other [32-34].

Also, the tribological performances of materials respectively of coatings have been extensively studied [35-37] by using tribometers according to the pin-on-disk method (POD).

In this paper, in addition to the cavitation erosion investigation, the results obtained through a professional tribometer using pin-on-disk method regarding the dry sliding wear resistance of the X5CrNi18-10 austenitic stainless steel are also presented.

2. Experimental procedure

The cavitation experimental stand consists the following components (figure 1): ultrasonic generator, piezoelectric-acoustic converter, mechanical transformer (with the role of amplifying the amplitude in the horn and in the sample), the water container (filled with distilled water) and the sample support. The water temperature is measured using a digital thermometer.

The steps for testing a sample are: cleaning and filling the water container, cleaning the sample and measuring its mass and starting the generator for tests. After the tests, using a digital balance, the sample mass is measured and the value is registered. If the mass loss of a sample is determined by weighing, the cavitation erosion rate is calculated by deriving the mass loss in relation with time.

It can be said that the generation of cavitation bubbles with the cavitation experimental stand differs from that encountered in the operation of hydraulic turbines, where some sediment, mud or sand are also encountered [1]. So, the mechanism of material erosion on this stand that simulates the cavitation bubbles is almost similar to the cavitation phenomenon that occurs in reality [38-40].

The CSM tribometer consists a sample disk and a counter body (in this research a ball 100Cr6 steel with 6 mm diameter was used). The radius on the sample is adjustable and the load and speed are predefined (figure 2). Measurements can be performed with or without lubricants and under different environmental humidity conditions. The coefficient of friction (CoF) is displayed in real time and the wear rate is achieved by measuring the wear track and determining the material volume loss.

The experimental methodology on the two stands took into account the parameters described above, as shown in G32-92 and G32-10 standards (both for cavitation erosion tests) and ASTM G99-95a standard (for dry sliding wear tests).

Regarding the X5CrNi18-10 austenitic stainless steel samples, the dimensions were Φ16x10 mm and the cavitation erosion tests were done in four periods of 180 minutes respectively on an extended duration of 1800 minute of cavitational attack. The dry sliding wear tests required only 83 minutes.

The testing parameters are shown in table 1 and table 2 and the mechanical properties respectively the chemical composition of X5CrNi18-10 are presented in table 3 and table 4.
Figure 1. Scheme of cavitation experimental stand components and principle of the stationary specimen method.

Figure 2. Principle of the pin-on-disk method.

Table 1. Parameters for cavitation erosion tests.

| Frequency (kHz) | Amplitude (µm) | Water temperature (°C) | Horn and sample distance (mm) |
|----------------|----------------|-------------------------|--------------------------------|
| 20 ±0.5        | 50             | 25 ±2                   | 0.6                            |

Table 2. Parameters for dry sliding wear test.

| Load (N) | Linear speed (cm·s⁻¹) | Motor speed (rpm) | Radius (mm) | Distance (m) | Humidity (%) | Temperature (°C) |
|----------|------------------------|-------------------|-------------|--------------|--------------|------------------|
| 10       | 15                     | 474.33            | 3.02        | 750          | 50           | 20               |

Table 3. X5CrNi18-10 mechanical properties.

| Tensile strength Rm (N·mm⁻²) | Yield strength Rp 0.2 (N·mm⁻²) | Elongation at yield A (%) |
|------------------------------|---------------------------------|--------------------------|
| 605                          | 294                             | 58.4                     |

Table 4. X5CrNi18-10 chemical composition (wt.%).

| C    | Cr   | Mn   | Co   | N    | Ni   | P    | Si   | Cu   | Fe   |
|------|------|------|------|------|------|------|------|------|------|
| 0.02 | 18.231 | 1.415 | 0.087 | 0.086 | 8.141 | 0.031 | 0.022 | 0.369 | 0.446 | 71.15 |

The high chromium and nickel content of this steel make it very resistant to corrosion [41], but also to cavitation erosion [42,43], as will be see from the research results.
3. Results and discussion

3.1. Cavitation erosion results
For the multiple tests of 180 minutes respectively for the extended duration of 1800 minutes, in table 5 some of the cavitation erosion results are presented comparatively.

| Samples (sur)faces | Cumulated time | Period | Sample mass Before test | After test | Max. mass loss | Max. cumulative | Max. cavitation rate |
|--------------------|----------------|--------|-------------------------|------------|---------------|-----------------|---------------------|
| Sample 1-Face 1    | 180            | 15     | 16309.43                | 16308.69   | 0.15          | 0.74            | 1.480               |
| Sample 1-Face 2    | 180            | 15     | 16308.69                | 16308.18   | 0.12          | 0.51            | 0.580               |
| Sample 2-Face 1    | 180            | 15     | 16122.91                | 16122.1    | 0.11          | 0.81            | 1.220               |
| Sample 2-Face 2    | 180            | 15     | 16122.11                | 16121.3    | 0.14          | 0.81            | 1.040               |
| Sample 1-Face 2    | 1800           | 60     | 16308.17                | 16256.18   | 2.74          | 51.99           | 2.520               |

The graphs of cumulative mass loss and cavitation erosion rate versus time curves are shown in figure 3 and figure 4 for the multiple tests of 180 minutes respectively in figure 5 and figure 6 for the extended duration of 1800 minutes.

Figure 3. Cumulative mass loss vs time (180 min).

Figure 4. Cavitation erosion rate vs time (180 min).

Figure 5. Cumulative mass loss vs time (1800 min).

Figure 6. Cavitation erosion rate vs time (1800 min).
From the all tests of 180 minutes, regarding the mass loss, it can say that the four (sur)faces have lost eroded material as follows: 0.74 mg for Sample 1 - Face 1, 0.51 mg for Sample 1 - Face 2, 0.81 mg for Sample 2 - Face 1 and also 0.81 mg for Sample 2 - Face 2.

So the Sample 1 - Face 2 with less material loss and also the lowest value of cavitation erosion rate was subjected further for an extended duration of 1800 minutes, where after this test the total material loss was only 51.99 mg with a cavitation erosion rate not more than 2.520 mg h\(^{-1}\).

Some images of the sample tested for 1800 minutes are shown in figure 7.

![Sample images](image_url)

**Figure 7.** Images of Sample 1 - Face 2 after 1800 minutes of cavitation attack a) macrophotography and b) microstructure (Magn. 250X - 100 μm).

From figure 7 it can be see that the surface was heavily eroded in the center with crakes and microcrakes respectively had shallow erosions in the adjacent zones.

### 3.2. Dry sliding wear results

The research on the dry sliding wear resistance of the X5CrNi18-10 austenitic stainless steel have follow to obtain results in two directions, namely: determination of friction coefficient and wear rate. These results as shown in figures 8 and 9 respectively in tables 6 and 7.

![Coefficient of friction vs time and distance curve](image_url)

**Figure 8.** Coefficient of friction vs time and distance curve.

![Wear track profiles](image_url)

**Figure 9.** Wear track profiles of a) ball; b) sample; c) 3D view and d) digital micrograph.
The cavitation erosion has been formed in the cavitation area of the rotor blades, with the wear track profiles (which were acquired with a digital microscope and a confocal 3D laser scanning microscope), the length and the width of the ball wear was 1.87 mm respectively 1.40 mm and regarding the sample, the volume loss of it was 0.7733 mm³ and the wear rate value was 1.03·10⁻⁴ mm² N⁻¹ m⁻¹ (table 7).

### 4. Conclusions

The paper has referred to the cavitation erosion as a result of the cavitation phenomenon that occurs in the working environment of the rotors / rotor blades of hydraulic turbines and to the cavitation erosion research purpose which is to discover materials with a very good cavitation erosion resistance and respectively regarding the tribological performance of materials by using tribometers according to the pin-on-disk method (POD).

In this way, the cavitation erosion and dry sliding wear behavior of X5CrNi18-10 austenitic stainless steel through many tests regarding the cumulative mass loss and cavitation erosion rate respectively regarding the coefficient of friction and the wear rate was investigated and it was found that the X5CrNi18-10 austenitic stainless steel possess a very good cavitation erosion resistance respectively has a low dry sliding wear resistance.

The cavitation erosion results obtained from mass loss and cavitation erosion rate curves highlighted a slowly cavitation erosion mechanism with some cracks, microcracks respectively shallow erosions.

For the satisfactory dry sliding wear results, the values of friction coefficient are characteristic for the steel-steel friction value range (0.46 – 0.85) and correlated with the wear rate values, it is indicate that the material destruction was quite intense.

### 5. References

[1] Singh R, Tiwari S K and Mishra S K 2012 *J Mater Eng Perform* 21(7) 1539-51
[2] Machuta J and Nová I 2015 *Manufacturing Technology* 15(4) 591-6
[3] Monteiro W A, Pereira S A L and Vatavuk J 2017 *Journal of Metallurgy* 2017 1-7
[4] Ivan A, Ivan M and Both I 2010 *WSEAS Transactions on Applied and Theoretical Mechanics* 5(3) 187-96
[5] Tugui C A, Vizureanu P, Iftimie N and Steigmann R 2016 IOP Conf. Series: Materials Science and Engineering, Romania, June 09-10, pp 1-8
[6] Bereteu L, Bordeașu I, Drăgănescu G, Simoiu D, Micu L and Sâlceanu C 2015 *Appl Mech Mater* 801 317-22
[7] Bordeașu I, Popoviciu M O, Salcianu L C, Ghera C, Micu L M, Badarau R, Iosif A, Pirvulescu

---

**Table 6. Friction coefficient values.**

|       | Start | Min   | Max   | Mean | Std. Dev. |
|-------|-------|-------|-------|------|-----------|
| 0.188 | 0.124 | 0.873 | 0.642 | 0.088 |

**Table 7. Wear rate results.**

| Wear track depth, \( h \) (\( \mu m \)) | Wear track width, \( s \) (\( \mu m \)) | Cross section area, \( A \) (\( \mu m^2 \)) | Volume loss, \( V \) (\( mm^3 \)) | Wear rate, \( K \) (\( mm^2 N^{-1} m^{-1} \)) |
|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|
| 44.496                                 | 1381.881                               | 41023.99                               | 0.7733                                 | 1.03·10⁻⁴                              |
L D and Podoleanu C E 2016 IOP Conference Series: Materials Science and Engineering, Romania, May 25-26, pp 1-11

[8] Ghera C, Mitelea I, Bordeasu I and Craciunescu C 2016 METAL 2016, Czech Republic, April 25-27, pp 706-11

[9] Murgan I, Digulescu A, Candel I, Cornil I and Şerbănescu A 2017 Oceans 2017, Anchorage, September 17-22, pp 1-5

[10] Ghian B, Bordeasu I, Chiban N, Badarau R, Hadar A and Serban N 2008 DAAAM, Slovakia, October 22-25, pp 541-2

[11] Dunca G, Bucur D M, Isbăşoiu E C, Călincau C and Ghercu C M 2012 UPB Scientific Bulletin, Series D: Mechanical Engineering 74(1) 59-66

[12] Candel I, Bunea F, Dunca G, Bucur D M, Ioana C, Reeb B and Ciocan G D 2014 IOP Conference Series-Earth and Environmental Science, Canada, September 22-26, pp 1-8

[13] Digulescu A, Murgan I, Candel I, Bunea F, Ciocan G, Bucur D M, Dunca G, Ioana C, Vasile G and Şerbănescu A 2016 IOP Conference Series-Earth and Environmental Science, France, July 04-08, pp 1-10

[14] Kekes D, Psyllaki P, Vardavoulias M and Vekinise G 2014 Tribology in Industry 36(4) 375-83

[15] Da Cruz J R, Henke S L and Monteiro A S C 2016 Materials Research 19(5) 1033-41

[16] Li D G, Chen D R and Liang P 2017 Ultrason Sonochem 35 375-81

[17] Cînea L, Hatiegan C, Pop N, Negrea R, Reduca E, Gillich G R, Dănuţ M, Nedeloni M D 2016 Appl Therm Eng 103 1164-75

[18] Ciubotariu C R, Frunza Verde D, Marginean G, Şerban V A and Bîrdeanu A V 2016 Opt Laser Technol 77 98-103

[19] Bordeasu I, Micu L M, Mitelea I, Utu I D, Pirvulescu L D and Sirbu N A 2016 Mater Plast 53(4) 781-86

[20] Ciubotariu C R, Frunza Verde D, Secosan E, Marginean G and Campian V 2016 Stroj Vestn-J Mech E 62(3) 154-62

[21] Montesano L, Gelfi M, Pola A and La Vecchia G M 2015 Procedia Engineer 109 228-33

[22] Gottardi G, Tocci M, Montesano L and Pola A 2018 Wear 394-395 1-10

[23] Nová I and Machuta J 2016 Manufacturing Technology 16(1) 225-30

[24] Pola A, Montesano L, Tocci M and La Vecchia G M 2017 Materials 10(3) 1-13

[25] Petrogalli C, Montesano L, Pola A, Gelfi M, Ghidini A and LaVecchia G M 2015 Procedia Engineer 109 154-61

[26] Montesano L, Gelfi M, Pola A, Colombi P and La Vecchia G M 2013 Metall Ital 9(2) 3-11

[27] Mahmoud E R I 2015 IJERT 4(08) 422-7

[28] Chawla K, Saini N and Dhiman R 2013 IOSR-JMCE 9(4) 18-22

[29] Ozgowicz W, Kalinowska-Ozgowicz E and Kuru A 2008 Archives of Materials Science 32(1) 37-40

[30] Nedelcu D, Cojocaru V, Nedeloni M, Peris-Bendu F and Ghican A 2015 Mechanika 4 272-6

[31] Nedeloni M D, Hatiegan C, Vasile O, Hamat C O, Fania C and Gillich N 2015 RJAV 12(2) 155-60

[32] Lupinca C I, Nedeloni M D and Nedelcu D 2014 Mater Sci Forum 782 269-74

[33] Potoceanu N, Nedeloni M D, Chirus D and Florea D 2014 Mater Sci Forum 782 257-62

[34] Nedeloni M D, Potoceanu N, Florea D and Chirus D 2014 Mater Sci Forum 782 251-6

[35] Kazamer N, Pascal D T, Marginean G, Serban V A, Brandl W and Valean P C 2016 NANOCON pp 383-8

[36] Kekes D, Psyllaki P and Vardavoulias M 2014 Tribology in Industry 36(4) 361-74

[37] Rozing G, Alar V and Marušić V 2015 Interdisciplinary Description of Complex Systems 13(3) 461-471

[38] Bena T, Mitelea I, Bordeasu I and Craciunescu C 2016 METAL 2016, Czech Republic, May 25-27, pp 653-8

[39] Bordeasu I, Micu L M, Mitelea I, Utu I D, Pirvulescu L D and Sirbu N A 2016 Mater Plast
[40] Salcianu C L, Bordeasu I, Mitelea I and Craciunescu C M 2016 METAL 2016, Czech Republic, May 25-27, pp 843-8
[41] Rozing G, Alar V, Marušić V and Samardžić I 2016 Metalurgija 55(3) 441-444
[42] Padurean I, Bordeasu I, Velescu C and Oanca O 2007 Rev Roum Sci Tech Ser Mec Appl 52(1) 15-26
[43] Padurean I and Nedelcu D 2008 Rev Roum Sci Tech Ser Mec Appl 55(3) 203-215
[44] Bonny K, De Baets P, Vleugels J, Van der Biest O, Salehi A, Liu W and Lauwers B 2009 Int J Refract Met H 27 449-457
[45] Cozza R C 2013 Surf Coat Tech 215 224-233
[46] Fox-Rabinovich G S, Gershman I, El Hakim M A, Shalaby M A, Krzansowski J E and Veldhuis S C 2014 Lubricants 2 113-123

Acknowledgment
We are very grateful to Mr. Prof. Viorel Câmpian from the Eftimie Murgu University of Reșița and to Mrs. Dr. Gabriela Mărginean from the Westphalian University of Applied Sciences Gelsenkirchen for the laboratory equipment.