Evaluation of the cavitation resistance of some materials based on mean durability

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1. Introduction

The ASTM G32-2010 International Standards recommend the materials behavior evaluation at cavitation erosion, generated in the vibratory device, by curves and parameters which define degradation degree of the exposed surfaces at cavitation, expressed by the amount of material removed by cavitation, the caverns dimension produced, respectively the speeds with which they occur [1-2]. Some laboratories have another derivation parameters, which allow for a more suggestive evaluation, resulting from the comparison criterion [1], [4-6]. For example, in the Cavitation Laboratory of the Polytechnic University of Timisoara, also uses the normalized resistance at cavitation (R_{ns}) and the roughness parameter (R_z) of the eroded surface [5]. In the same way, prof. K. Steller [4], using various results, obtained in the Gdansk Laboratory, the most on the rotating disc apparatus, proposes the mean durability parameter (δ_{med}). Although the materials used in this papers are tested in another type apparatus, that generates cavitation on the principle of sound vibrations, it is checked whether parameter (δ_{med}), introduce by K. Steller, offer the same conclusion, in terms of the hierarchy after resistance to erosive intensity of vibratory cavitation.

2. Materials and methods of research

The tested materials are three stainless steel, in annealed state, with different structures (OH12NDL- the reference steel in our Laboratory [2], [5], 17-4 PH semi-austenitic stainless steel [7], X2CrNiMoN22-5-3 duplex steel [8] and X5CrNi18-10 austenitic steel [9, 10]) and a CuAl10.5Ni5Fe4.8Mn1.5 high-strength bronze (also known as AMPCO M4) [11].

In the tables 1 and 2 are presented the chemical compozitions and the mechanical properties, determinated in the speciality laboratories at Polytehnica University of Timisoara.

Table 1. The chemical compositions.

Material	C	Si	Mn	Ni	Cr	Mo	Al	Other elements	N	Cu	P	S
OH12ND												
17-4 PH	0.10	0.50	1.56	4.12	15.57	2.11	0.58	2.04 Co	0.046	0.18	0.031	0.029
X2CrNiMoN22-5-3	0.017	0.72	1.8	5.02	22.08	2.9	-	-	0.16	-	0.021	0.012
X5CrNi18-10	0.046	0.89	1.46	8.11	17.95	-	-	0.16 W	-	0.27	0.024	0.019
AMPCO M4	-	-	1.41	4.85	-	-	10.46	4.72 Fe	-	78.56	-	-

Table 2. The mechanical and physical properties.

Material	Hardness HB	Tensile Strength, Ultimate R_m [N/mm^2]	Min. elongation at fracture A_5 [%]	Tensile Strength, Yield, $R_{p\,0,2}$ [N/mm^2]	Modulus of Elasticity E [N/mm^2]	Density ρ [g/mm^3]
OH12NDL	225	650		400	$210 \cdot 10^9$	7.81 [1, 2]
17-4 PH	387	1276	10	1103	$211 \cdot 10^9$	7.75 [7]
X2CrNiMoN22-5-3	275	736	28	545	$190 \cdot 10^9$	7.82 [8, 12]
X5CrNi18-10	183	550	45	195	$193 \cdot 10^9$	7.9 [9, 10]
AMPCO M4	286	980	8	789	$124 \cdot 10^9$	7.45 [11]

The tests have realized on the vibratory device with the piezocermic crystals of the Polytechnic University of Timisoara, Figure 1.

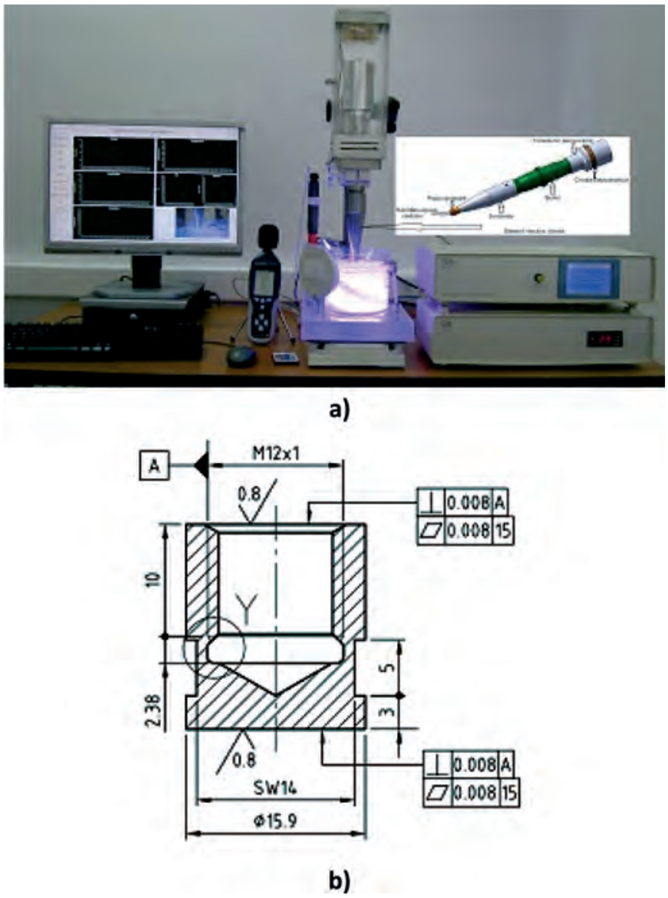

Figure 1. Vibratory apparatus:
a) image device; b) specimen detail.

The preparation and testing procedures at cavitation (165 minutes exposure time, divided into 12 periods: one by one 5 and 10 minutes and 10 by 15 minutes each), are specific to the Laboratory and in accordance with ASTM G32-2010 International Standards.

The functional parameters of the apparatus , controlled and maintained at the values prescribed for the test regime, for the five metals, are: the power of the ultrasonic electronic generator (500 W); vibration frequency (20000 ± 200 Hz); duble amplitude of the vibrations (50 µm); water temperature (22 ± 1^{o}C).

All tests was realized in double distilled water, using specimens made according with figure1.b

3. Results and discussions

The experimental results obtained for the three samples were mediated and then were used to plot the approximate characteristic curves for volume losses, Figure 2 and the corresponding erosion rates, Figure 3.

These curves are described by the equations established by the team led Bordeasu whose shapes are [2], [5]:

- for the volume losses:

$$V(t) = A \cdot t \cdot (1 - e^{-B \cdot t}) \qquad (1)$$

- for the erosion rate:

$$v(t) = A \cdot (1 - e^{-B \cdot t}) + A \cdot B \cdot t \cdot e^{-B \cdot t} \qquad (2)$$

The values of the coefficients A and B, statistically established on the condition of obtaining the best approximation, are included in Table 3.

Table 3. The values of the coefficients A and B.

Material	A	B
OH12NDL	0.0316	0.035
17-4 PH	0.013	0.018
X2CrNiMoN22-5-3	0.0162	0.035
X5CrNi18-10	0.0195	0.021
AMPCO M4	0.0142	0.04

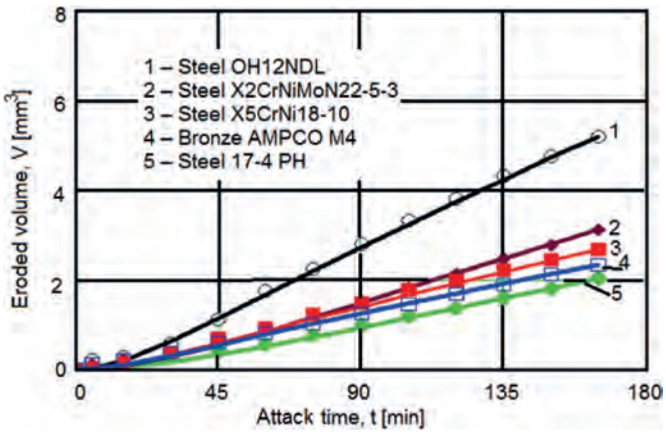

Figure 2. Evolution eroded volume against cavitation exposure time.

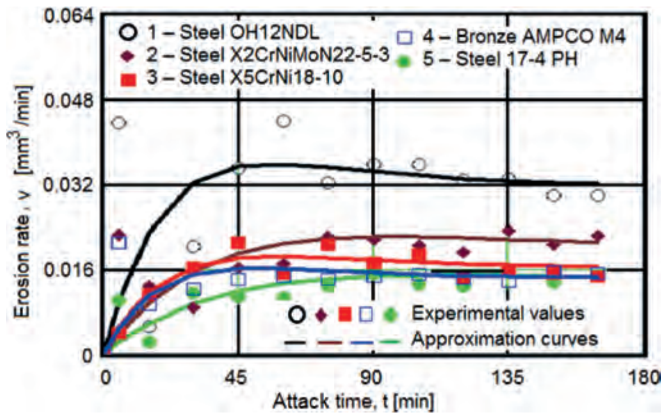

Figure 3. Evolution of erosion rate against cavitation exposure time.

The evolution of the curves, from the two figures suggests the next ordering after increasing the resistance to the vibratory cavitation attack.

1 - the OH12NDL stainless steel - considered with good resistance to cavitation, because him has conferred a long duration service life for the turbine blades form Power Plants ”Porțile de Fier I”, with small welding repair interventions after about a year.

2 - the X2CrNiMoN22-5-3 duplex stainless steel, due to the presence of ferrite, the constituent with the low resistance to cavitation erosion.

3 - the X5CrNi18-10 austenitic stainless steel;

4 - the AMPCO M4 naval bronze with high resistance;

5 - the 17-4 PH stainless steel with indirect transformation

The custom of the Laboratory of Cavitation of the ”Politehnica” University of Timișoara custom and the ASTM G32-2010 norms, show that the parameters which described very good the resistance to vibratory cavitation are mean depth erosion (MDE) and mean depth erosion rate (MDER). Of this reason, in the Figures 4 and 5, are rendered these curves.

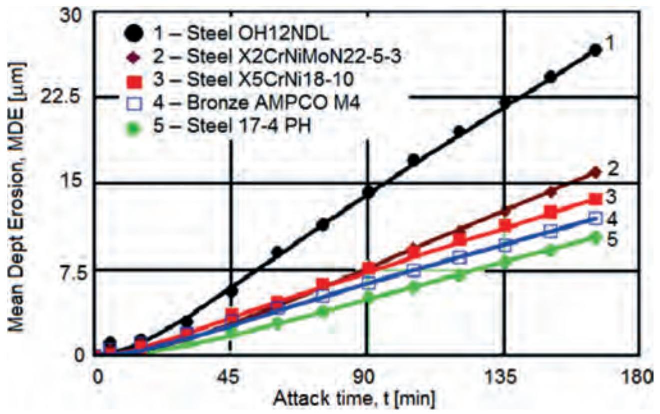

Figure 4. Evolution of mean depth erosion against cavitation exposure time.

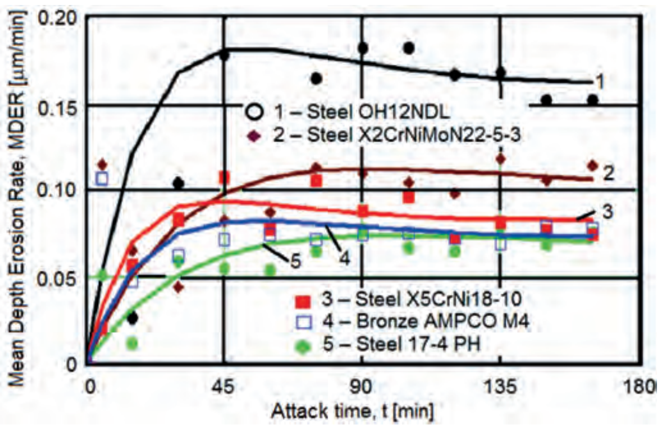

Figure 5. Evolution of mean depth erosion rate against cavitation exposure time.

The experimental values, obtained in the intermediary test periods were determined with the relations [5]:

- mean depth erosion penetration for a single interval:

$$\Delta MDE_i = \sum_{i=1}^{12} \left(\frac{4 \cdot \Delta V_i}{\pi \cdot d_p^2}\right) \tag{3}$$

- cumulative mean depth penetration:

$$MDE_i = \sum_{i=1}^{12} \Delta MDE_i \tag{4}$$

- mean depth penetration rate for an interval:

$$MDER_i = \Delta MDE_i / \Delta t_i \tag{5}$$

where:

i – testing period (1…12)

ΔV_i – eroded volume in the period “i”, in mm3,

Δt_i – cavitation exposure time for the period “i” (5 minutes, 10 minutes or 15 minutes)

d_p – diameter of the specimen (d_p = 15.8 mm),

As expected, as a form of evolution, these curves are similarly to those that which carcaterize of the volume to the expelled material and the rate with which it is expelled (see figures 2 and 3).

As the purpose of the work is to highlight, by comparison, the hierarchy according with the values of the mean durability parameter recommended by K. Steller, these values were determined with the relationship below [4]:

$$\delta_{med} = \frac{165 \cdot (e^{3 \cdot \alpha} - 1)}{3 \cdot \alpha \cdot V_{max}} \tag{6}$$

where:

$$\alpha = \frac{3}{165} \cdot \left(\frac{165 \cdot V_{max} - \int_0^{165} A \cdot t(\cdot 1 - e^{-B \cdot t})dt}{165 \cdot V_{max}}\right) \tag{7}$$

and V_{max} it is maximum lost volume in 165 minutes, conformable the dates (figure 2) and from the histogram (figure3).

In histogram, from Figure 6, are compared the values of these the four parameters.

Dates by this table shows the dependence of the mean durability to the expulsed material volume, the differences values to the etalon steel being same.

This aspect is a important indice, wich characterized of the material by point of view of the resistance and the comportation, but don’t ilustration the destruction extension in the surface depth, exposed to the microjets and shock waves, generated in the cavitation time.

The parameters, wich offers the such indications are the mean erosion depth and the rate with wich those penetrate in the structure of the surface of the material.

The dates by thable 4, with refering to the comparison of the five materials, taking as reference of the OH12NDL etalon steel, it is noted:

1 - for the 17-4PH semi-austenitic inoxydable steel the volume of material expelled in 165 minutes (V_{max}) and the durability (δ_{med}) increases with about 61 %, and mean depth erosion (MDE) increases with about 60 % and erosion rate (MDER), to wich to tends stabilize, with about 56 %;

2 - for the X2CrNiMoN22-5-3 duplex inoxydable steel the volume of material expelled in 165 minutes (V_{max}) and the

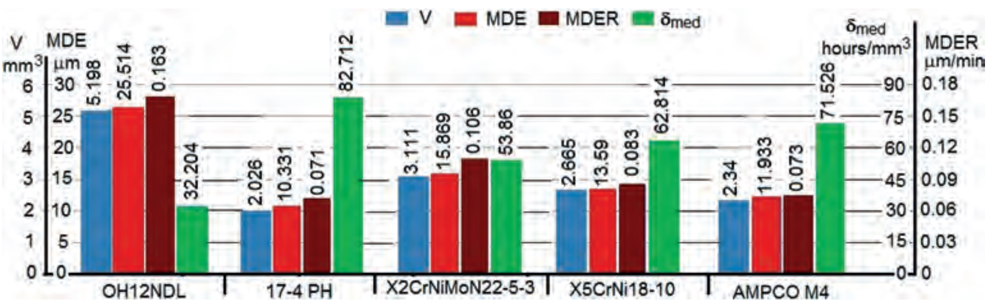

Figure 6. Evaluation parameters of the cavitation resistance.

Table 4. Comparisons between the characteristic parameters values of the OH12NDL steel (appreciation of the cavitation resistance).

No.	Material	$V_1 - V_i$ (i = 2...5)	$MDE_1 - MDE_i$ (i = 2...5)	$MDER_1 - MDER_i$ (i = 2...5)	$\delta_{med\ i} - \delta_{med\ 1}$ (i = 2...5)
1	OH12NDL	0	0	0	0
2	17-4 PH	3.172 (61 %)	15.183 (60%)	0.092 (56%)	50.508 (61 %)
3	X2CrNiMoN22-5-3	2.087 (40%)	9.645 (38%)	0.057 (35%)	21.656 (40%)
4	X5CrNi18-10	2.533 (49%)	11.924 (47%)	0.08 (49%)	30.61 (49%)
5	AMPCO M4	2.858 (55%)	13.521 (53%)	0.09 (55%)	39.322 (55%)

durability (δ_{med}) increases with about 40 %, and mean depth erosion (MDE) increases with about 38 % and erosion rate (MDER), to wich to tends stabilize, with about 55 %;

3 - for X5CrNi18-10 austenitic inoxydable steel the volume of material expelled in 165 minutes (V_{max}) and the durability (δ_{med}) increases with about 49 %, and mean depth erosion (MDE) increases with about 47 % and erosion rate (MDER), to wich to tends stabilize, with about 49 %;

4 - for the high-resistance bronze AMPCO M4, the volume of material expelled in 165 minutes (V_{max}) and the durability (δ_{med}) increases with about 55 %, and mean depth erosion (MDE) increases with about 53 % and erosion rate (MDER), to wich to tends stabilize, with about 55 %

Because, some materials, as high-resistance bronze and X5CrNi18-10 stainless steel, the mean durability (δ_{med}) has the similar values with the erosion rate (MDER), confirm the K. Steller theory to use this parameter at the evaluation of the cavitation resistance.

4. Concluzions

Based on the results presented and the analyze conducted we can to affirm:

1. the mean durability (δmed) it is a parameter which permit the evaluation of the materials resistance of cavitation, according to standard application times, without giving clear information about their behavior on during the attack;

2. for the five materials used in this paper, the mean durability parameter leads to the same hierarchy as that given by the MDE and MDER (from the cavitation stabilization zone), used in the Cavitation Laboratory of the Polytechnic University of Timisoara and recommended by ASTM G32 norms.

References

[1]. Anton I. 1985, Cavitatia, vol.I, Editura Academiei R.S.R., Bucuresti

[2]. Bordeaşu I. 2006, Eroziunea cavitațională a materialelor, Editura Politehnica, Timişoara

[3]. Franc J. P., Kueny J. L., Karimi A., Fruman D. H., Fréchou D., Briançon-Marjollet L., Billard J. Y., Belahadji B., Avellan F., Michel J. M. 1995, La cavitation. Mécanismes physiques et aspects industriels, Press Universitaires de Grenoble, Grenoble, France

[4]. Steller K., Reymann Z., Krzysztoowicz T., Evaluation of the resistance of materials to the cavitational erosion, Procedings of the fifth Conference on Fluid Machinery, Vol 2, Akad Kiado, Budapest, 1975

[5]. Oanca O. V., 2014, Tehnici de optimizare a rezistenței la eroziunea prin cavitație a unor aliaje CuAlNiFeMn destinate execuției elicelor navale, Timisoara Polytehnic University, Romania, Doctoral Thesis

[6]. *** Standard test method for cavitation erosion using vibratory apparatus, ASTM G32-2010

[7]. ***https://www.azom.com/article.aspx?ArticleID=6778

[8]. ***http://www.lucefin.com/wp-content/files_mf/1.4462en.pdf

[9]. ***http://www.steelnumber.com/en/steel_composition_eu.php?name_id=100

[10]. ***http://www.lucefin.com/wp-content/files_mf/1.4301en.pdf-X5CrNi18-10

[11]. ***http://www.matweb.com/search/DataSheet.aspx?MatGUID=6a6ed08ba3d34b56a45af5fcc28251f5,

[12]. *** http://www.ampcometal.com/common/datasheets/en/AM4_EX_E.pdf