

A new concept for stainless steels ranking upon the resistance to cavitation erosion

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Abstract. In present, the ranking of materials as their resistance to cavitation erosion is obtained by using laboratory tests finalized with the characteristic curves mean depth erosion against time MDE(t) and mean depth erosion rate against time MDER(t). In some previous papers, Bordeasu and co-workers give procedures to establish exponential equation representing the curves, with minimum scatter of the experimental obtained results. For a given material, both exponential equations MDE(t) and MDER(t) have the same values for the parameters of scale and for the shape one. For the ranking of materials is sometimes important to establish single figure. Till now in Timisoara Polytechnic University Cavitation Laboratory were used three such numbers: the stable value of the curve MDER(t), the resistance to cavitation erosion ($R_{cav} \equiv 1/MDER_{stable}$) and the normalized cavitation resistance R_{ns} which is the rate between $v_s = MDER_{stable}$ for the analyzed material and $v_{se} = MDER_{se}$ the mean depth erosion rate for the steel OH12NDL ($R_{ns} = v_s/v_{se}$). OH12NDL is a material used for manufacturing the blades of numerous Kaplan turbines in Romania for which both cavitation erosion laboratory tests and field measurements of cavitation erosions are available. In the present paper we recommend a new method for ranking the materials upon cavitation erosion resistance. This method uses the scale and shape parameters of the exponential equations which represents the characteristic cavitation erosion curves. Till now the method was applied only for stainless steels. The experimental results show that the scale parameter represents an excellent method for ranking the stainless steels. In the future this kind of ranking will be tested also for other materials especially for bronzes used for manufacturing ship propellers.

1. Introduction

The concern of the researchers in ranking the materials after the cavitation erosion resistance is a very old one, perhaps the first attempt were made by Parsons in 1883 [1] preoccupied for ship propellers and afterwards by Pilaev and Edel interested in hydraulic turbines [2].



With the increasing of the studies the problem was analyzed by numerous researchers such as Garcia-Hammit (1960) [3], Thiruvengadam (1963) [4], Heymann (1970) [5], Noskiewicz (1983) [6], Sakai & Shima (1987) [7], Bordeasu (1997) [8], [9]. It was put into evidence the influence of various factors such as the chemical composition, the mechanical characteristics, the heat treatments and metallographic structure, etc. For the laboratory devices the standardization recommended by ASTM for vibratory equipments [10] was extremely benefic. For a first rapid evaluation of different materials there is necessary a single figure. Till now as such a single figure was chosen from the following parameters: the final value of the lost mass/volume, the maximum value of the erosion rate, the stable value of the mean depth erosion rate or the inverted of the mean depth erosion rate ($R_{cav} \equiv 1/MDER$).

It must be noted that every model have its benefits and its limits. That is why the present contribution proposes a new concept of correlating the cavitation erosion resistance with the numerical values of the scale/shape parameters from the equations describing the cavitation erosion characteristic curves $MDE(t)$ and $MDER(t)$. It was observed that for numerous stainless steels tested in our laboratory only the scale parameter has great importance. In consequence we propose the use of this parameter as the most useful single figure method for rapid comparisons.

2. Methods for determining the cavitation erosion resistance

Commonly the cavitation erosion resistance is evaluated in all the important laboratories such as those in Michigan [3], Gdansk [11], Wuxi [8], Timișoara [6], [8], [12-17], respecting the new ASTM G32-2010 Standard [10]. After tests, the results are plotted as cavitation erosion characteristic curves and compared with a standard material for which the behavior both in laboratory and field conditions is known. In the comparisons there are considered one or more of the following parameters: the final slope of the cumulative mean depth erosion (MDE) curves (Fig. 1), the normalized cavitation erosion resistance, the mean depth erosion rate (Fig. 2), the incubation period, the time interval necessary to obtain some penetration depth, some mass loss or some volume loss. Because the deterioration degree of a certain material is strongly influenced by the test device running parameters it was necessary to establish the ASTM G32-2010 Standard for all laboratories. Until now, neither of the parameters indicated by the Standard ASTM G32-2010 is accepted as unique figure for establishing the cavitation erosion resistance [8].

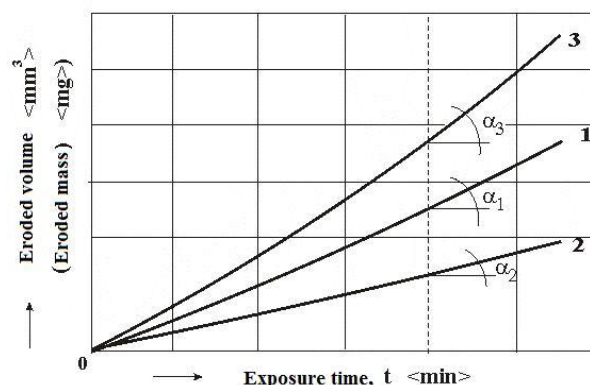


Figure 1. Ideal mean curves expressing the time variation of the eroded mass/volume [2]

1, 2, 3 – Materials with different cavitation erosion behavior

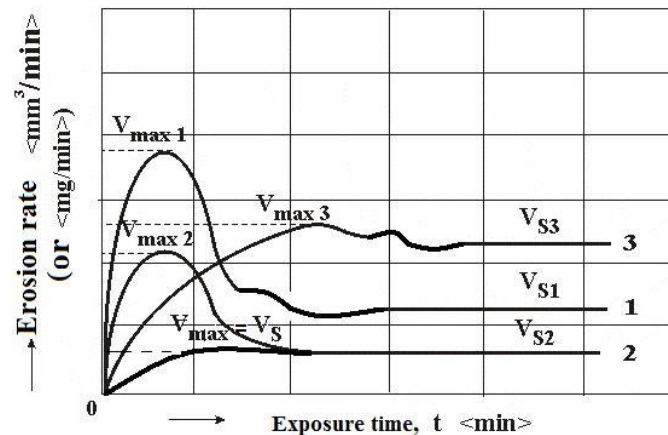


Figure 2. Ideal mean curves expressing the time variation of the erosion rate [2]

(v_{\max} - maximum value of the erosion rate; v_s - value of the stable erosion rate)

1, 2,3 – Materials with different cavitation erosion behavior

In Timisoara „Politehnica” University Cavitation Laboratory, taking into account the 70 years of experience in the field as well as the ASTM G32-2010 Standard recommendations, in order to characterize the resistance to cavitation erosions are used three parameters. Two of them represent the characteristic curves of the mean depth erosion MDE(t) and the mean depth erosion rate MDER(t) [3], [12], [15], [17]. Those curves for the tested material are compared with that of a standard material. This method is an excellent criterion to certify the behavior of various stainless steels, marine bronzes with or without hardening heat treatments or even for those pulverized with ceramics powders and afterward treated with laser beams [18]. The third one R_{ns} (normalized resistance) is a dimensionless parameter established by dividing the final rate (the stable value) of the researched material to that of the standard material. As standard material is used the stainless steel OH12NDL of Russian receipt for which we have both laboratory and field results (in Romanian Power Plants) for extremely long periods.

Below are presented the relations established by Bordeasu and co-workers [9], [12], [14], [16] used for plotting the curves MDE(t) and MDER(t) which allow to determine the parameters used for evaluation/comparison of the cavitation erosion resistance:

- for the mean depth erosion

$$\text{MDE}(t) = A \cdot t \cdot (1 - e^{-B \cdot t}) \quad (1)$$

- for the mean depth erosion rate

$$\text{MDER}(t) = A \cdot (1 - e^{-B \cdot t}) + A \cdot B \cdot t \cdot e^{-B \cdot t} \quad (2)$$

where: A is a scale parameter statistically established for realizing the approximation curve, with the condition of a minimum scatter for the measured points with regard to the curve;

B is a shape parameter.

The normalized resistance to cavitation erosion R_{ns} can be written as:

$$R_{ns} = v_s / v_{se} \quad (3)$$

where:

v_s - is a tendency value at which the erosion rate curve remains approximately stable (regardless of the criterion taken in to discussion: the eroded mass, the lost volume or the penetration depth);

v_{se} - is the same value for the standard material (for our laboratory the material employed is the stainless steel OH12NDL).

3. Researched materials. Test devices

The materials used in the present work are cast or rolled stainless steels, annealed, destined for manufacturing hydraulic machineries pieces subjected to intense cavitation. Because those steels are not standard ones, with the exception of the steel OH12NDL, for identification were used the following symbols CxCr_yNi_z, where:

x = 1; 036; 030; represent the carbon content (1- represent 0.1 %, 036 represent 0.036 %, 030- represent 0.030 %);

y = 2, 6, 10, 12, 13, 14, 16, 18, 24 – represent the approximate chromium content in %

z = 05, 2, 4, 6, 8, 10 - represent the approximate nickel content in %.

All the necessary data fore those steels were taken from the following references:

- for steels C1Cr6Ni10, C1Cr10Ni10, C1Cr18Ni10, C1Cr24Ni10, C036Cr13Ni10, C036Cr14Ni10, C036Cr16Ni10, C036Cr18Ni10, OH12NDL [15], [16],

- for steels C1Cr12Ni05, C1Cr12Ni2, C1Cr12Ni6, C1Cr12Ni10, C036Cr12Ni6, C036Cr12Ni8, C036Cr12Ni2, C036Cr12Ni4 [13], [14]

- for steels C030Cr12Ni2, C030Cr12Ni6 [17].

Table 1 gives the ranking after the normalized cavitation resistance presented by Jurchela and Karabenciov [14], [16]. In the same table are given also the structure of constituents determined by using the Schaffler diagram (see Fig.3).

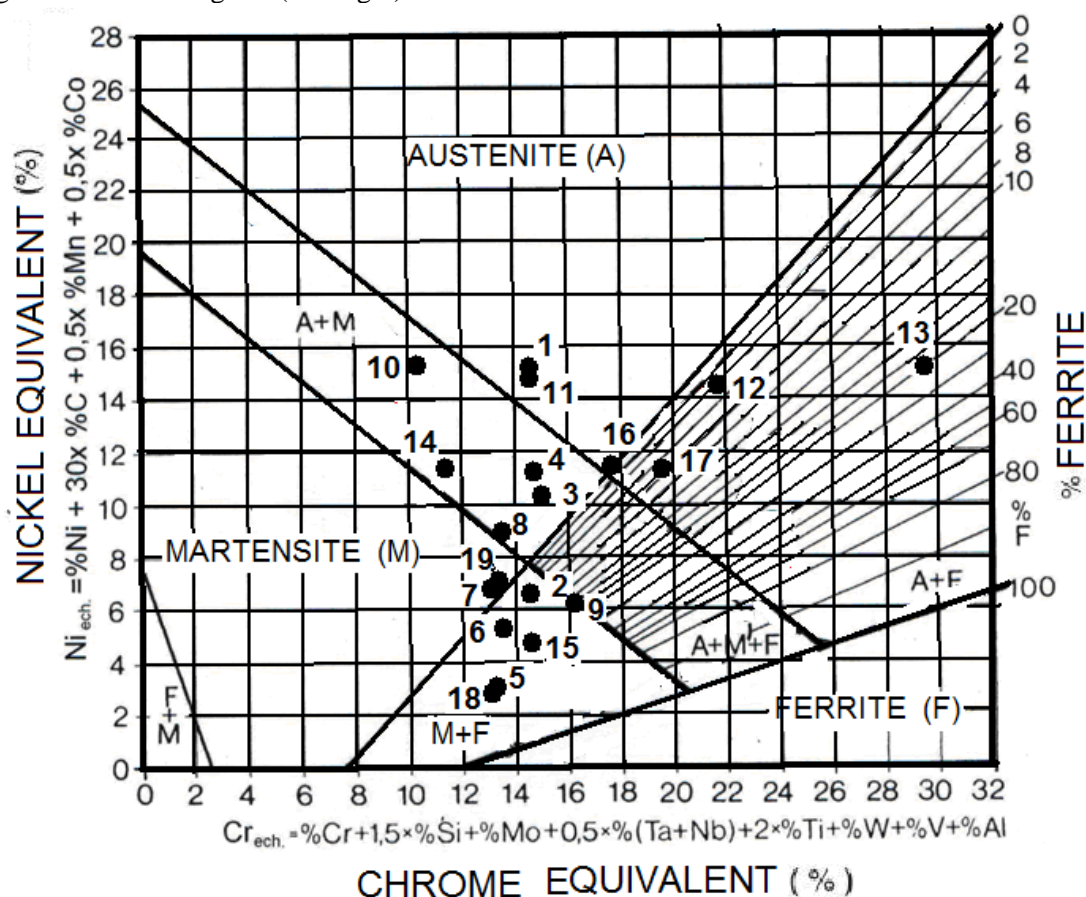


Figure 3. Position of the analyzed stainless steels in Schaffler diagram

1- C1Cr12Ni10, 2- C1Cr12Ni2, 3- C1Cr12Ni6, 4- C036Cr14Ni10, 5- C036Cr12Ni2, 6- C036Cr12Ni4, 7- C036Cr12Ni6, 8- C036Cr12Ni8, 9- OH12NDL, 10- C1Cr6Ni10, 11- C1Cr10Ni10, 12- C1Cr18Ni10, 13- C1Cr24Ni10, 14- C036Cr13Ni10, 15- C1Cr12Ni05, 16- C036Cr16Ni10, 17- C036Cr18Ni10, 18- C030Cr12Ni2, 19- C030Cr12Ni6

Table 1. Ranking of the steels after the normalized cavitation erosion resistance [9], [11]

Cavitation resistance	Material	R_{ns}	Structure
Super resistant, $R_{ns} < 0,2$	C1Cr12Ni6	0,11	60% A+40% M
Excellent $R_{ns} = [0,2 \div 0,4)$	C1Cr6Ni10	0,24	32% M + 68% A
	C1Cr12Ni10	0,29	100 % A
Very good $R_{ns} = [0,4 \div 0,8)$	C1Cr24Ni10	0,41	81% A + 19% F
	C1Cr18Ni10	0,43	98% A + 2% F
	C1Cr10Ni10	0,44	100% A
	C1Cr12Ni2	0,51	90% M+10% F
	C030Cr12Ni6	0,57	100 % M
	C036Cr12Ni8	0,59	90 % M +10% A
	C036Cr12Ni6	0,62	100 % M
	C036Cr13Ni10	0,73	55% M + 45% A
	C036Cr14Ni10	0,76	30% M + 70% A
Good $R_{ns} = [0,8 \div 1,6)$	C1Cr12Ni05	0,88	75% M+ 25 % F
	C036Cr12Ni2	0,88	55 % M+45 % F
	C036Cr12Ni4	0,88	86% M+14 % F
	C036Cr16Ni10	0,92	100% A
	OH12NDL	1,0	84% M+16% F
	C036Cr18Ni10	1,05	93% A + 7% F
	C030Cr12Ni2	1,14	40% M+60% F

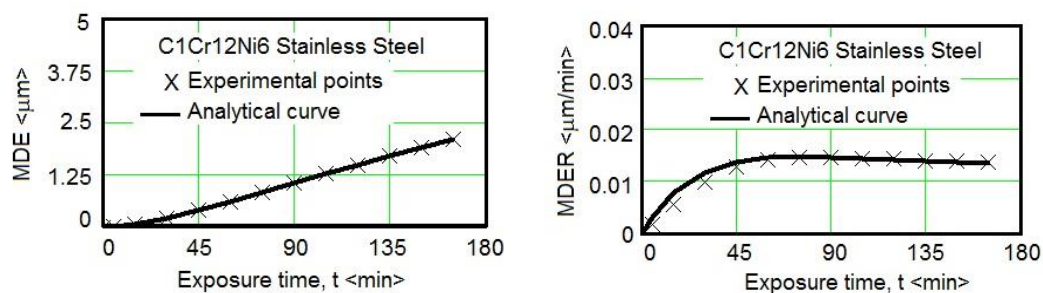
All the 19 steels were tested in the Timisoara „Politehnica” University Cavitation Laboratory using a device with piezoelectric crystals. All the testing conditions regarding the procedure and the installation parameters (vibration frequency and amplitude, power of the ultrasonic electric generator, specimen diameter, water temperature) were in conformity with the recommendation of the Standard ASTM G32-2010 and respecting the laboratory custom regarding: the total cavitation exposure, the intermediary measurement intervals, the state of the specimen surface, the preparation of the specimen before testing, preservation of the specimen during pauses between test intervals, the mass loss measurements and the construction of the specific curves [14], [16], [18], [19].

4. Correlation between cavitation erosion resistance and the parameters of characteristic curves

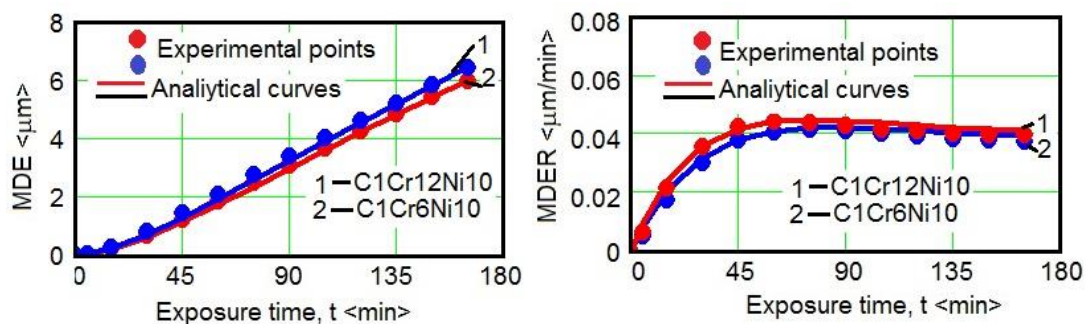
Figure 3 present the diagrams for each cavitation erosion resistance in conformity with the data of Table 1 by using the relation (2). Table 2 presents the values of the parameters A and B as well as the cavitation resistance defined by the relation (4):

$$R_{cav} = 1/MDER_s \quad (4)$$

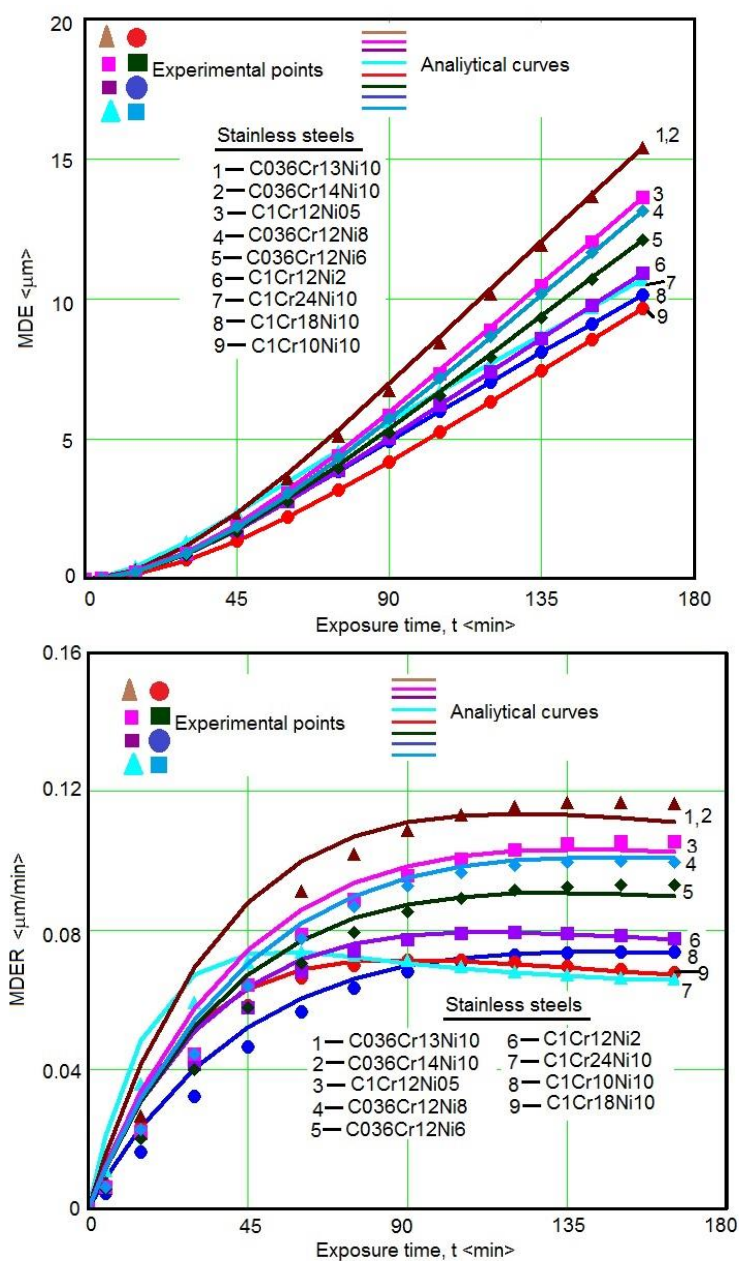
where $MDER_s$ is the mean depth erosion rate in the final stages (the constant level of MDER).



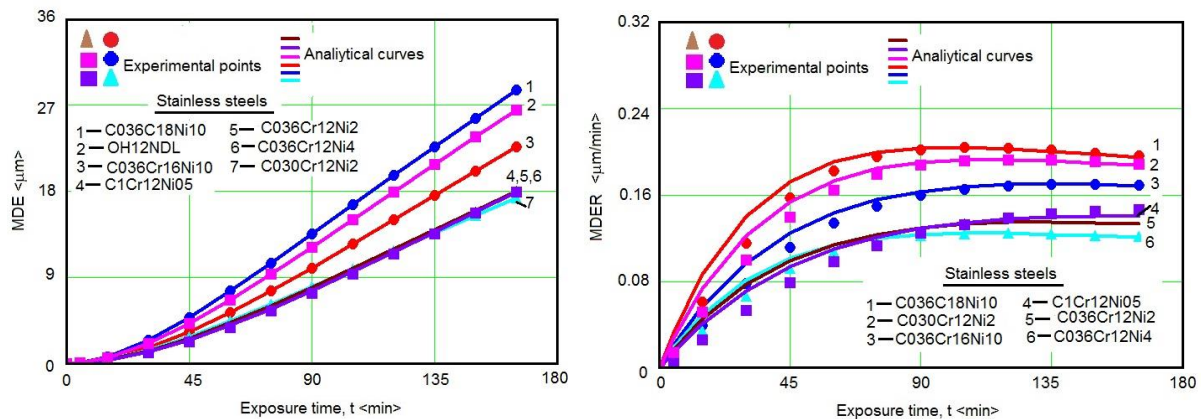
a) - cavitation erosion super resistant steel



b) - steel with excellent resistance



c) - steel with very good resistance



d) - steel with good resistance

Figure 4. Cavitation erosion characteristic curves

a- cavitation erosion super resistant steel; b-steel with excellent resistance; c- steel with very good resistance; d- steel with good resistance

Table 2 presents the values of the scale parameters A and shape parameters B for the mediation curves as well as the cavitation erosion resistance R_{cav} . The values are ranked after the parameter R_{ns} from Table 1.

Table 2. Ranking of steels after cavitation erosion resistance R_{cav} and comparisons with the values of scale and shape parameters

Cavitation erosion	Material	R_{cav}	Parametru A	Parametru B
Super resistant	C1Cr12Ni6	78	0.013	0.027
Excellent	C1Cr6Ni10	23	0.040	0.022
	C1Cr12Ni10	22	0.037	0.024
Very good	C1Cr24Ni10	14	0.066	0.025
	C1Cr12Ni2	13	0.070	0.018
	C1Cr18Ni10	13	0.068	0.014
	C1Cr10Ni10	13	0.067	0.013
	C036Cr12Ni6	11	0.080	0.015
	C036Cr14Ni10	10	0.090	0.015
	C036Cr12Ni8	10	0.090	0.013
	C030Cr12Ni6	10	0.086	0.016
	C036Cr13Ni10	9	0.100	0.017
	C1Cr12Ni05	8	0.110	0.018
Good	C036Cr12Ni2	7	0.120	0.014
	C036Cr12Ni4	7	0.120	0.014
	C036Cr16Ni10	6	0.150	0.015
	OH12NDL	5	0.170	0.018
	C036Cr18Ni10	5	0.180	0.020
	C030Cr12Ni2	5	0.191	0.026

In Figure 5 is presented the correlation between the cavitation erosion resistance R_{cav} and the parameter A. It can be seen that this variation is approximate exponential.

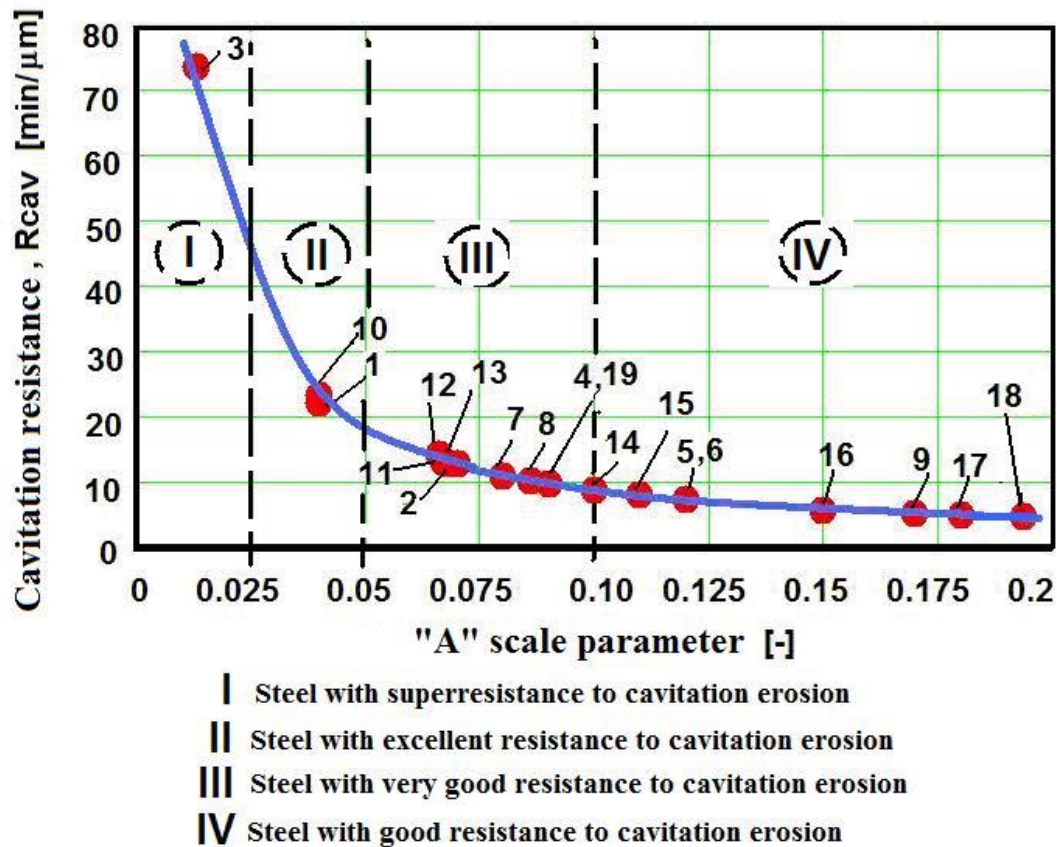


Figure 5. Correlations between cavitation erosion resistance and the scale parameter A

1- C1Cr12Ni10, 2- C1Cr12Ni2, 3- C1Cr12Ni6, 4- C036Cr14Ni10, 5- C036Cr12Ni2, 6- C036Cr12Ni4, 7- C036Cr12Ni6, 8- C036Cr12Ni8, 9- OH12NDL, 10- C1Cr6Ni10, 11- C1Cr10Ni10, 12- 1Cr18Ni10, 13- C1Cr24Ni10, 14- C036Cr13Ni10, 15- C1Cr12Ni05, 16- C036Cr16Ni10, 17- C036Cr18Ni10, 18- 030Cr12Ni2, 19- C030Cr12Ni6

Taking into account the ranking in Tables 1 and 2 it is observed that the same ranking can be obtained also by using the parameter A, respecting the same principle (doubling the interval limits at passing from one class to another). In consequence, the resistance classes for the cavitation erosion of stainless steels, for the Cavitation Laboratory of Timisoara Polytechnic University have the following limits:

- super resistant for $A < 0.025$
- excellent resistance for $A \in [0.025-0.05)$
- very good resistance for $A \in [0.05-0.1)$
- good resistance for $A \in [0.1-0.2)$

This variation manner shows that the value of parameter A is dependent on the material characteristics, at least for stainless steels. The researches must be extended also to other materials.

The dependence on the cavitation intensity is difficult to be appreciated. In consequence the comparisons with good standard materials used long time in industrial facilities (especially power plants) remains a necessity. If in the future will appear great differences between the laboratory result and the industrial behavior this is a signal that the laboratory devices must be modified to have the same type of cavitation as those encountered in the industrial installations.

Figure 6 shows that the shape parameter B of the relations (1) and (2) do not have significant influences upon the cavitation resistance and can not be used for rankings. Regardless of the resistance

class, for the stainless steels its value is comprised in the interval (0.012-0.028) and no correlation between R_{cav} and B can be established.

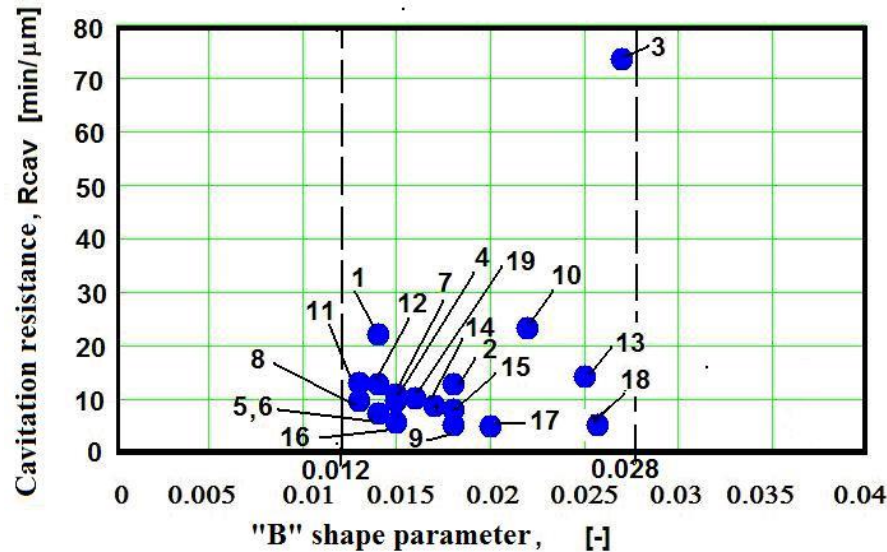


Figure 6. Correlations between cavitation erosion resistance and the shape parameter B
 1- C1Cr12Ni10, 2- C1Cr12Ni2, 3- C1Cr12Ni6, 4- C036Cr14Ni10, 5- C036Cr12Ni2, 6- C036Cr12Ni4,
 7- C036Cr12Ni6, 8- C036Cr12Ni8, 9- OH12NDL, 10- C1Cr6Ni10, 11- C1Cr10Ni10, 12-
 C1Cr18Ni10, 13- C1Cr24Ni10, 14- C036Cr13Ni10, 15- C1Cr12Ni05, 16- C036Cr16Ni10, 17-
 C036Cr18Ni10, 18- C030Cr12Ni2, 19- C030Cr12Ni6

On the other hand, analyzing the shape of the curves $MDER(t)$ from Figure 4 it resulted, that regardless the resistance class, the value of this parameter depends on the curve shape (with a pronounced maxim, with an extended maxim or with the steady value equal with the maxim one). It is possible that the value of this parameter to be dependent on the surface quality at the beginning of the cavitation and not to the mechanical characteristics or the intensity of the hydrodynamic phenomena.

This is consistent with values of B equal for steels placed in different classes (for example the value of B is approximate the same for the super resistant steels - C1Cr12Ni6 - and those with good resistance - C1Cr24Ni10 and C030Cr12Ni2 -).

5. Conclusions

1. The scale parameter A, from the equations (1) and (2) is used for representing the cavitation erosion characteristic curves but it can be chosen as a representative numeric value for the cavitation erosion resistance, in vibratory devices, playing the same role as the normalized resistance R_{ns} .
2. The reference steels (for example OH12NDL) are materials subjected to cavitation both in laboratory devices and in field condition (for example the cavitation erosion resistance of OH12NDL was examined during 40 years in the Iron Gates Power Plant). The comparison with such a steel give great assurances regarding the behavior of the new material, chosen in laboratory conditions. The comparisons are possible also by using the values of the parameter "A".
3. The scale parameter "A" can be used also for establishing the classes of behavior to cavitation erosion.
4. The shape parameter "B" from relations (1) and (2) being is determined by the state of the specimen subjected to cavitation which dictates the behavior in the first moment of exposure, can not be used as cavitation erosion ranking criterion. The influence of this criterion there must be undertaken in future analyses, on large classes of materials (carbon steels, stainless steels, bronzes etc.), to establish the manner in which their values are influenced by the nature of the material.

5. The use of the scale parameter must be considered as a very good single figure for comparisons of cavitation erosion behavior but, for exhaustive analyses, must not exclude the use of the characteristic curves, especially MDE(t).

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