METHOD FOR CLASSIFYING STAINLESS STEELS UPON CAVITATION RESISTANCE

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Abstract

Until now, for specialists in the field, classification of materials upon cavitation erosion resistance, represent an unsolved problem, in spite of numerous experimental results obtained with different laboratory facilities. The present work is a contribution intended to give some clarifications, in order to solve that problem. In our opinion, materials can be grouped in five resistance categories: weak, good, very good, excellent, and super-resistant. In conformity with ASTM G32 Standard, the parameters used for classification are the normalized resistance to cavitation erosions R_{ns} and $R_{n\ max}$. In our work as reference material was used the OH12NDL stainless steel, employed in the past for manufacturing numerous hydraulic turbines, with good cavitation erosion resistance. In order to develop the method, were tested various stainless steels, in a special device realized in the Hydraulic Machinery Laboratory of Timisoara Polytechnic University. In this facility, the cavitation erosion is produced by vibrating a nickel tube. Both the characteristic cavitation erosion curves (which give the variation in time of erosion) and the images of the eroded microstructures show that the developed method is useful for classifying stainless steels used in manufacturing hydraulic turbines.

Key words: stainless steel, cavitation erosion resistance, cavitation erosion characteristic curves, vibratory devices, hydraulic turbines, pumps, ship propellers

1. INTRODUCTION

A great concern, for numerous research laboratories [2], [3], [7] is the cavitational erosion resistance prediction as a function of the material (chemical composition, metalographic structure and mechanical characteristics) on the one hand and the intensity of the cavitation on the other hand. The exisence of a classification of materials from the point of view of cavitation erosion resistance is of great interest for designers, manufactureres and hydraulic plant running staff. Interesting results were publishe recently in France (Frank [3]), USA (Garcia [4]), Japan (Hattory [6]), etc. These results are obtained both through laboratory researches, on various test facilities, as well as on industrial running machines. Unfortunately, these results are not complete satisfatory because the erosion process depends simultaneously on a multitude of hydrodynamic factors and of factors bounded to the material composition and structure. The present paper presents a classification method based on the experimental results obtained in Timisoara Hydraulic Machinery Laboratory with a vibratory test facility.

2. RESEARCHED MATERIALS, FACILITIES AND METHODS

The results presented in the paper are based on cavitation erosion tests upon 12 stainless steels of the type used both for manufacturing and repair work of machine details heavy subjected to cavitation erosion (hydraulic turbine runners, pump impellers and ship propellers). For 8 stainless steels the chemical composition has under 0.1 % carbon, 4 having constant chromium content (12 %) and variable nickel content (between 0 and 10%), 4 having constant nickel (10%) and variable chromium (between 6 and 24%). The other 4 steels have chemical composition used frequently for industrial purposes [2]. The final heat treatment consists in quenching followed by ageing through tempering.

The cavitation erosion tests were conducted on the T1 magnetostrictive device [1, 2], using a vibratory specimen [5]. The running parameters are: power 500 W, vibration frequency 7000±0.3% Hz, vibration double amplitude 94 µm, specimen diameter 12 mm, supply voltage 220V/50Hz. The tests were conducted in double distilled water at a constant temperature of 21 $\pm$ 1 ^{0}C.

3. EVALUATION OF EXPERIMENTAL RESULTS

The analyze of numerous data accumulated at Timisoara Hydraulic Machinery Laboratory, in over 50 years of experience, generated the question: which are the limits to consider a material to be

A) super-resistant to cavitation erosion,

B) excellent resistant,

C) very good resistant,

D) good resistant, or

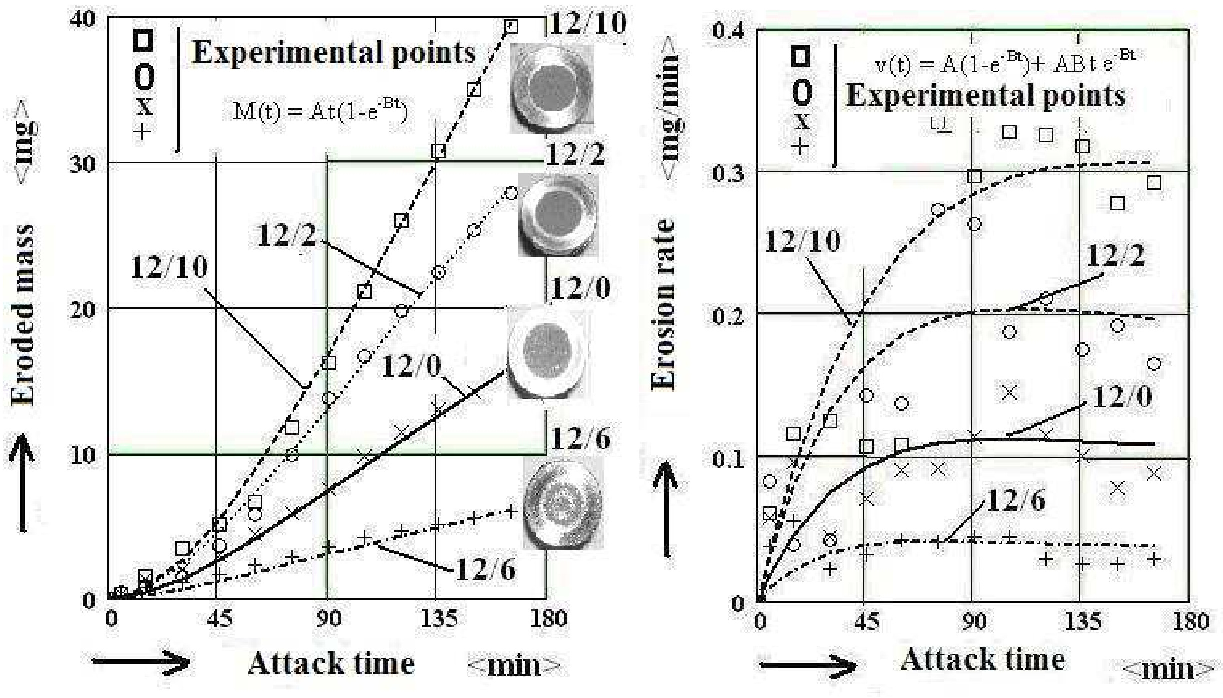
E) weak resistant ?

One of the following procedures does evaluate the cavitation erosion intensity, in the majority of studies:

1. Analyzing the slope of the curves giving the variation of the eroded mass m(t) or the eroded volume V(t), during the exposure time, Fig. 1a, with the slope for the standard material;

2. Comparing the maximum (v_{max}) or stable (v_s) erosion rates values, between the tested and the standard material Fig. 1 b;

3. – Comparing: the maximum penetration depth MDP (measured**,** Fig. 2, or computed using ASTM Standards [7]), or the mean penetration rate, MDPR [3], with the equivalent parameters obtained for the standard material. This method is used, in present, on a smaller scale.



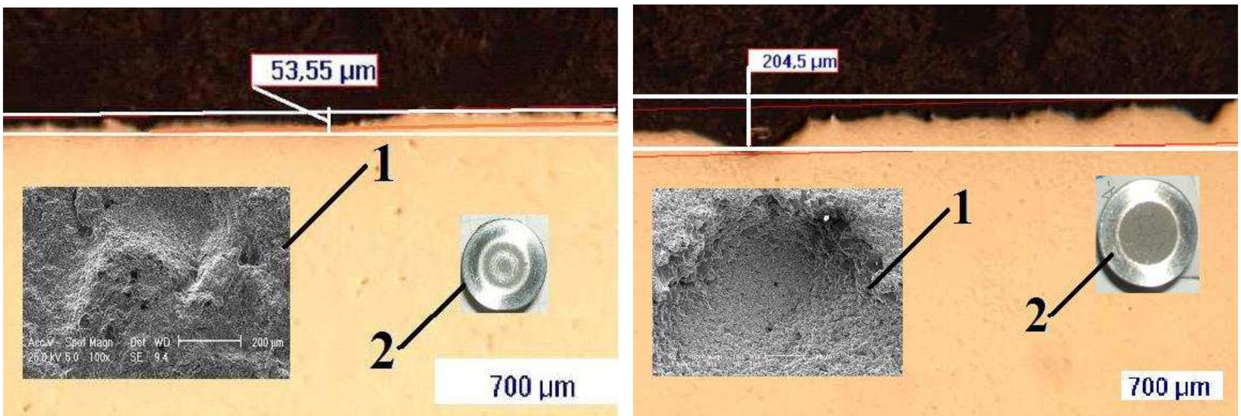
a) b)

Fig.1 Cavitation erosion characteristic curves for steels with constant chromium

a) Cumulative mass losses against time, b) Erosion rate against time

(Steel symbols represent chromium concentration over nickel concentration)

The characteristic curves presented in Fig. 1a and 1b show the best material, from those tested, but does not give indications if it is an excellent or a week material, unless if it is compared with a standard material, well known on the international market.
On the other hand, the maximum penetration depth produced by cavitation, Fig. 2, measured at the final exposure time (in our case 165 minutes) is not always in agreement with the behavior presented by the characteristic curves (exemplified in fig. 1). The maximum penetration depth depends always on the local conditions (dimensions of the expelled grains and the structural homogeneity). The use of normalized resistance to cavitation R_{ns} şi $R_{n\ max}$, according with the ASTM G32-2008 Standard [7] allow an objective classification .



a) 12/6 stainless steel b) 12/10 stainless steel

Fig. 2 Images of erosions, both on the attacked surface and in cross section x100
(after 165 minutes of cavitations attack)

1- Aspect of the attacked surface for final exposure time (SEM-Scanning Electron Microscope - x100)
2 –Stereo-microstructure aspects of attacked surface (magnification x8);

Consequently, the realization of a cavitation erosion classification method, allowing an adequate selection of the material, depending on the intensity of cavitation, is a stringent necessity.
The computation of the parameters R_{ns} şi $R_{n\,max}$, in conformity with the ASTM Standard, is given by (1) and (2).

$$R_{ns} = \frac{v_s}{v_{se}} \quad (1)$$

$$R_{n\,max} = \frac{v_{\max}}{v_{\max e}} \quad (2)$$

Where: v_s, v_{se}, and $v_{max\ e}$, (the indexes “e” refers to standard steel) represent the maximum and stabilization velocity values, given in Fig.2, and defined through relations of the form (for exponential regression equartions):

$$v(t) = A \cdot \left(1 - e^{-B \cdot t}\right) + A \cdot B \cdot e^{-B \cdot t} \quad (3)$$

Usually, as standard material is chosen steel with acceptable resistance to cavitation. For Michigan University Laboratory, as standard material, was taken the stainless steel 304 SS [5]. In our laboratory (THML), we choose the stainless steel OH12NDL, with good cavitation erosion qualities, used in the past for manufacturing numerous hydraulic turbine runners.
The proposed method to classify the steel is by using the parameters Rns and $R_{n\,max}$, in correlation with the chemical composition. In order to define the limits of different classes, it must be observed that for excellent cavitation resistance the limits must be closer than for weak cavitation erosion resistance. Table 1 gives the values of those limits in a decreasing order.

Table 1 Limits for different cavitation erosion zones

Class	Super-resistant	Excellent	Very good	Good	Weak
R_{ns}	< 0,2	0,2 ÷ 0,4	0,4 ÷ 0,8	0,8 ÷ 1,6	> 1,6
$R_{n\,max}$	<0,25	0,25 ÷ 0,5	0,5 ÷ 1,0	1,0 ÷ 2,0	> 2,0

The limits were established using the rule of doubling the interval for each transition from a superior to an inferior class. The rule was applied for both classification criteria (upon R_{ns} and R_{max}). The procedure corresponds to the criteria of enlarging the inferior classes but has no other theoretical support. With these chosen limits resulted the classification presented in Table 2.

Table 2 Classification upon the parameters $R_{n\,s}$ şi $R_{n\,max}$

Cavitation erosion resistance	Material	Parameter		
		$R_{n\,s}$	$R_{n\,max}$	R_{nmax} / $R_{n\,s}$
Super-resistant	12/6	0,1	0,01	0,1
Excellent	12/0	0,27	0,31	1,15
	6/10	0,33	0,4	1,21
	Inox III RNR	***0,39***	***0,33***	0,84
Very good	X20Cr13	0.54	***0,46 (Excellent)***	1,47
	10/10	0,44	0,51	1,16
	18/10	0,46	0,53	1,15
	12/2	0,48	0,56	1,17
	24/10	0,5	0,58	1,16
	12/10	***0,75***	***0,72***	0,96
	X10CrNi18/4PH	0,77	0,67	0,87
Good	OH12NDL	1,00	1,00	1,29

Data in Table 2 show a good agreement for the classification after R_{ns} and R_{nmax}.. A single exception appears, for the X20Cr13 steel, recorded with very good resistance according to R_{ns} and excellent according to R_{nmax}, but in both classification this material is placed at the border of the respective classes (see Table 1). We recommend the use of R_{ns} classification as the principal one. It is interesting to note that in every class appear important differences of the rate R_{nmax}/R_{ns} for different materials (see Table 2).
For verifying the method we use the experimental results of Garcia [4], upon six steels tested in Michigan Laboratory (Table 3), also with a vibratory device (A = 25,4 µm, f = 20 kHz, d = 14,3 mm). The standard material for this apparatus is the stainless steel 304 SS.

Table 3 Parameters and characteristics of materials tested by Garcia [4]

Material	$R_{n\,s}$	$R_{n\,max}$	MDPR µm/h	Cavitation erosion resistance
Carbon steel	2,0	2,3	5,8	weak
304 SS (standard steel)	1,0	1,0	2,54	good
316 SS	0,9	0,9	2,28	good
Mo -1/2 Ti	0,9	0,9	2,28	good
Cb- I Zr	1,5	1,5	3,7	good
Cb I Zr (A)	1,8	1,8	4,57	good

We found that for both used parameters the materials are correctly classified, taking into account their chemical composition. Applying this method in the future, for a larger range of steels, more beneficial information can be obtained and the method can be improved.

3a. Correlations between the cavitation erosion specific parameters with both chemical composition and microscopic structure

Taking into account the results, we use the curves presented in Fig. 3-4 to classify the stainless steels, tested in our laboratory, after the rate Cr_e/Ni_e which establishes the nature and the proportion of the structural constituents (see the Schäffler diagram [2]). The rate Cr_e/Ni_e takes into consideration the influence of chemical composition upon the cavitation erosion resistance. The curves in the diagram put into evidence what value of the rate Cr_e/Ni_e gives the best cavitation erosion resistance. In the same time this rate offers also information upon the steel structure. From the diagrams we can see that stainless steels with different chemical composition may have the same behavior to the erosion. From the diagrams result that for the values $Cr_e/Ni_e \cong 1.0 \div 2.0$ the cavitation erosion resistance increases, probable the best value being $Cr_e/Ni_e \cong 1.8$

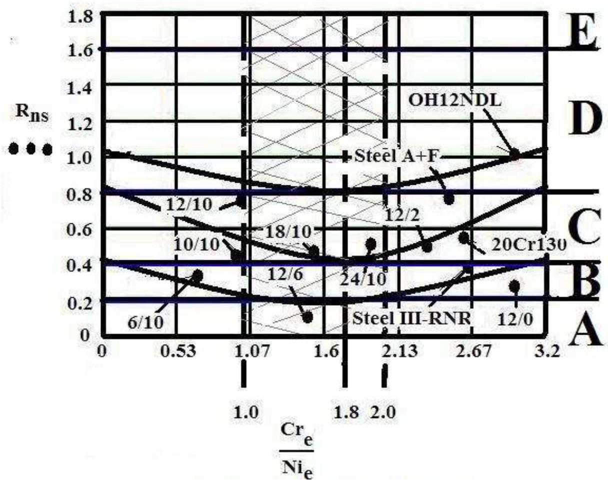


Fig.3 Steels classification using both the normalized resistance R_{ns} and the rate Cr_e/Ni_e

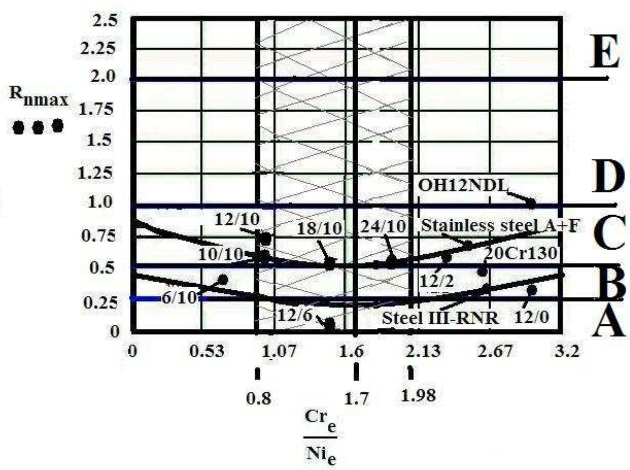


Fig.4 Steels classification using the normalized resistance R_{nmax} and the rate Cr_e/Ni_e

(A - super-resistant, B - excellent resistance, C - very good res., D - good res., E - weak resistance)

3b. Correlation between specific cavitation erosion parameters and steel mechanical properties

Using the procedure described at the point 3a, in Fig. 5 we correlate the normalized resistances with both the mechanical properties and the chemical composition, expressed in a single figure noted ψ. The ψ expression is a generalization of the Sakai-Shima procedure and was presented in 1998 by Bordeasu [1].

A very good agreement with the classification presented at the point 3a was obtained, so this diagram is also recommended for anticipating the behavior of different steels to cavitation erosion. In Fig. 5, the number of the zones with respect to the abscissa ψ was reduced to three. The zones D and E (see Cap. 3) were merged into the domain I (and even so, it remains a very small one) and the zone D (weak resistant) is in the exterior of the zone III and was not noted.

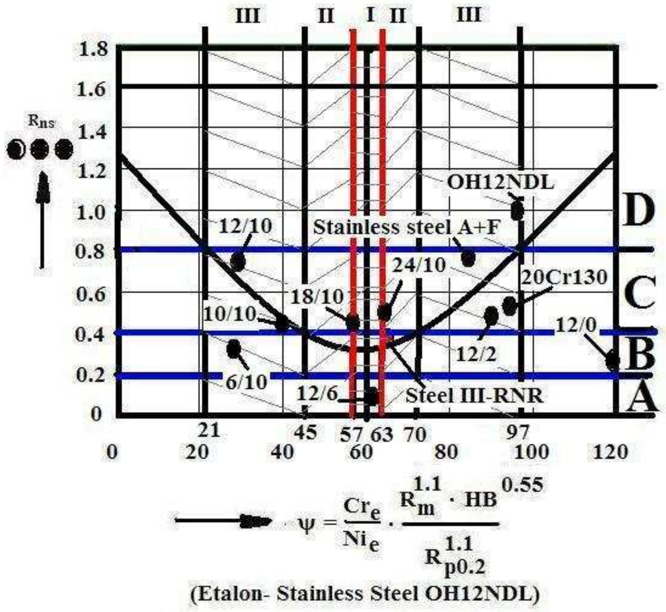


Fig. 5 Influence of chemical constitution and mechanical properties of steels upon the normalized cavitation erosion resistance

I - super and excellent resistance; II –very good resistance; III – good resistance

4. CONCLUSION

The proposed method for classifying the steels from the point of view of cavitation erosion resistance is adequate and justified because it offer a rapid orientation for material selection.

To anticipate the cavitation erosion for a stainless steel which is selected for hydraulic equipments there can be used the diagrams presented in the paper.

It was found a grouping of steels with great cavitation erosion resistance in the range $Cr_e/Ni_e \cong 1.0 \div 2.0$, with a tendency of optimization toward the value $Cr_e/Ni_e \cong 1.8$.

Acknowledgments

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