INFLUENCE OF THE SOLUTION TREATMENT TEMPERATURE UPON THE CAVITATION EROSION RESISTANCE FOR 17-4P.H. STAINLESS STEEL

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Abstract

Cavitation erosion is a key factor for extending the running life of hydraulic turbines blades or even runners. Our researches are directed towards new stainless steels composition with reduced carbon content but high cavitation erosion resistance and simultaneously good welding abilities and mechanical resistance. Various steels, with constant Ni content and variable Cr content (alpha gene element) present modifications of the nature and proportions of the constitutive structural components (Austenite, Martensite and Fe_{δ}) with important consequences upon the cavitation erosion resistance and the value of mechanical characteristics.

The cavitation erosion tests were done on a vibratory facility with piezoceramic crystals, realized in agreement with the specifications of the ASTM G32-2010 Standards. The obtained results show that a Cr content of about 6 % give the longest incubation period and the best cavitation erosion resistance, both values being better that those obtained with the steel OH12NDL used in the past, in Romania, on a large scale, for turbine components subjected to cavitation erosion.

Keywords: stainless steel, cavitation erosion, mechanical properties, vibratory test facility

1. INTRODUCTION

Cavitation erosion is the most spectacular effect of the cavitational phenomena, due to the destruction of the solid materials which represent the frontiers that come in contact with the cavitating fluid. For this reason the research done in this field is aimed towards generating new materials, especially stainless steels, with structural characteristics and mechanical properties which improve the resistance and the behavior to the destructive effect of cavitation [1], [2], [3], [4], [5], [6], [7]. This paper highlights the cavitation erosion resistance obtained on a range of eight stainless steels with about 10% nickel content by changing the chromium and carbon content, change which results in various microstructural constitutions.

2. STUDIED MATERIALS

The stainless steels studied in this paper belong to the range of stainless steels intended for the manufacturing of blades and rotors of hydraulic pumps and turbines operating in intense cavitation conditions. The studies were conducted on eight stainless steels divided in two groups, according to the carbon content: four with ≈ 0.1% carbon, ≈ 10% nickel and variable chromium content (≈ 6%; ≈ 10%; ≈ 18%; ≈ 24%) and four with ≈0,036% carbon, ≈10% nickel and variable chromium content (≈13%;≈14%; ≈16%; ≈18%). Austenite is an important constituent for these steels. They were chosen because they can be easily welded during routine or major maintenance operations on rotors and blades of hydraulic machines [1].

The steel blanks were cast in the EMO 1200 R vacuum melting furnace with electron flux. The casting of the steels was followed by a heat treatment of quenching in solution at 1050°C and air cooling (for the steels with martensite content), or water cooling (for the steels with a structure of austenite or austenite and ferrite δ) respectively. Three specimens were manufactured out of each steel blank for the cavitation tests and other specimens were manufactured out of the same blanks for determining the mechanical properties. The roughness of each specimen's cavitation exposed surface was determined as a mean value of three tests conducted in different places on the surface.

Table 1 shows the mechanical characteristics and the microstructure of the studied steels. The microstructure was determined on the Schäffler diagram with the equivalent chromium (Cr_e) and nickel (Ni_e) content [2], [8]. Table 1 also shows the notation system used in this paper, since the studied steels are not standardized steels. This notation system is comprised of:

- the symbol for the reference chemical element Ni, followed by the number 10, which represents it's approximate value (in percent); all the steels have the same value;
- the symbol for the variable chemical element Cr, followed by a number representing the approximate content of the element, in percent;
- the letter C representing carbon, followed by the number 1 (for the steels with about 0.1% carbon) or the number 036 (for the steels with 0.036 carbon).

Table 1 Mechanical properties. Microstructure.

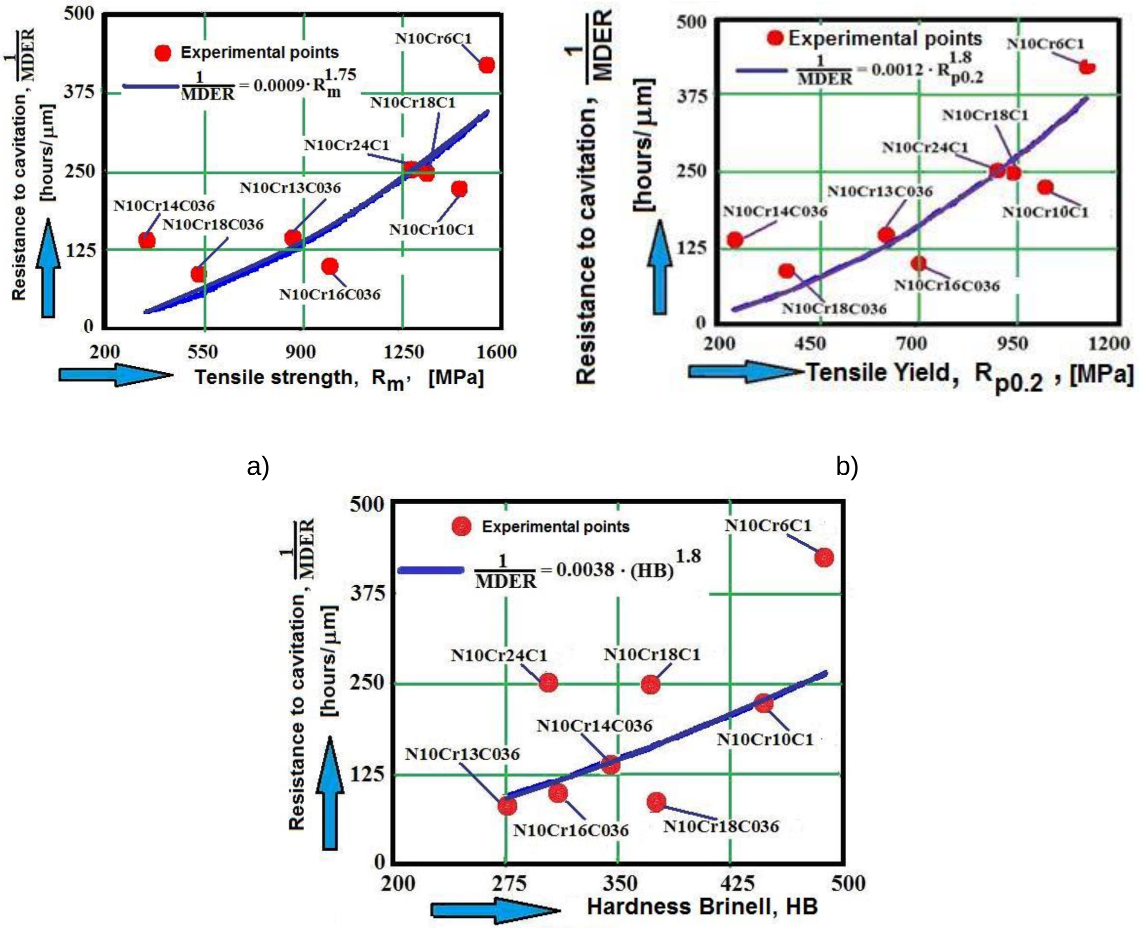
Steel	**Rm** [N/mm^2]	**Rp$_{0,2}$** [N/mm^2]	**HB**	**Cr$_e$** [%]	**Ni$_e$** [%]	**Structural constitution**
Ni10Cr6C1	1550	1120	489	11,924	15,173	32%M+68%F
Ni10Cr10C1	1450	1020	447	14,919	14,854	100%A
Ni10Cr18C1	1335	934	372	22,414	14,138	98%A+2%F
Ni10Cr24C1	1280	901	302	30,362	15,101	81%A+19%F
Ni10Cr13C036	856	618	276	13,209	11,454	55%M+45%F
Ni10Cr14C036	341	240	346	15,022	11,4935	30%M+70%F
Ni10Cr16C036	996	700	309	17,824	11,515	100%A
Ni10Cr18C036	527	369	375	19,610	11,508	93%A+7%F

3. TESTING METHOD

The cavitation tests were conducted on the vibratory apparatus with piezoceramic crystals T2 (double vibration amplitude 50 µm, vibration frequency 20000 Hz ± 3%, specimen diameter 15.8 mm, power of ultrasound generator 500 W) found in the Cavitation Laboratory of the Politehnica University of Timișoara [2]. The tests respected the procedures of ASTM G32-2010, using tap water kept at 22 ± 1°C [2]. The total duration of the cavitation tests was 165 minutes. The tests were stopped at predetermined intervals [5], [6], in order to take pictures of the eroded surface and to examine these surfaces with the naked eye and under the optical microscope. The mass loss registered during these stops was used to plot the diagrams for the mean depth of erosion MDE(t) and the mean depth of erosion rate MDER(t). Using the MDER(t) diagrams, we determined the 1/MDER parameter, which characterize the cavitation resistance of materials. This parameter is the inverse of the value at which the MDER parameter tends to stabilize.

4. EXPERIMENTAL RESULTS

Figure 1 shows the diagrams for the correlation of cavitation resistance 1/MDER with the main mechanical properties of the eight stainless steels studied in this paper.



a) b)

c)

Fig. 1 The variation of cavitation erosion resistance with the main mechanical properties: a) breaking strength, b) yield strength, c) Brinell hardness

As expected, the conclusion drawn from the three diagrams in Figure 1 is that the cavitation resistance increases exponentially with the value of the three mechanical properties R_m, $R_{p0,2}$ and HB. Also, it can be seen that the forms of the analytical formulas for the approximation curves are similar to the ones established by Garcia and Hammitt for the correlation of the 1/MDER parameter with the Brinell hardness (HB) [9].

Table 2 shows the values for the scale parameter A and the shape parameter B, used in the three curves that approximate the correlation points between the cavitation resistance parameter 1/MDER and the values for the mechanical properties.

Table 2 The analytical forms of the approximation curves

Figure	Analytical form	Parameter A	Parameter B
1 a	$1/MDER = A \cdot R_m^B$	0,0009	1,75
1 b	$1/MDER = A \cdot R_{p0,2}^B$	0,0012	1,8
1 c	$1/MDER = A \cdot HB^B$	0,0038	1,8

As one can see in Figure 1 and Table 2, the values for the shape parameters B are similar or identical to the value established by Garcia [9] and Hammitt [10], while the scale parameter A is completely different. We consider that difference of the scale parameter is due to its dependence on the measurement unit, to the reference mechanical property and to the cavitation damage intensity of the vibratory apparatus used in the experiments.

Figures 2 and 3 show the influence of the steels' microstructure on cavitation resistance (1/MDER) and on the mean depth of erosion (MDE) at the end of the cavitation tests. Also, these diagrams offer a ranking of the studied steels depending on the cavitation resistance.

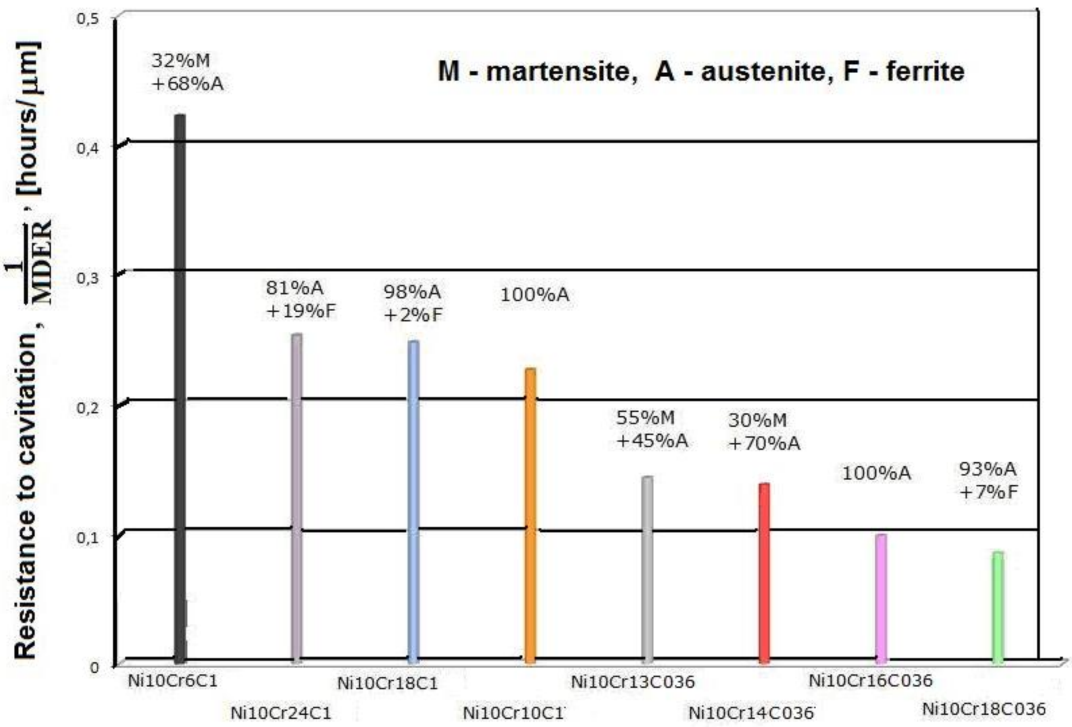


Fig. 2 The influence of microstructure on cavitation erosion

According to Figure 2, the highest cavitation resistance was registered for the steel with 0.1% carbon and 6% chromium, with a microstructure of 32% martensite and 68% austenite. The lowest cavitation resistance was registered for the steel with 0.036% carbon and 18% chromium, with 93% austenite and 7% ferrite.

Also, we can observe four groups of steels with similar cavitation resistance, but with different microstructures (shown from the strongest to the weakest):

1 - the highest cavitation resistance – the steel with 6% Cr and 0.1% C;

2 - the steels with 10% Cr, 18% Cr, 24% Cr and with 0.1% C;

3 - the steels with 13% Cr, 14% Cr and with 0/036% C;

4 - the steels with 16% Cr, 18% Cr and with 0.036% C.

Additionally, it is found that the steels with 0.1% C have a better cavitation resistance compared to the steels with 0.036% C, regardless of the chromium content or the microstructure.

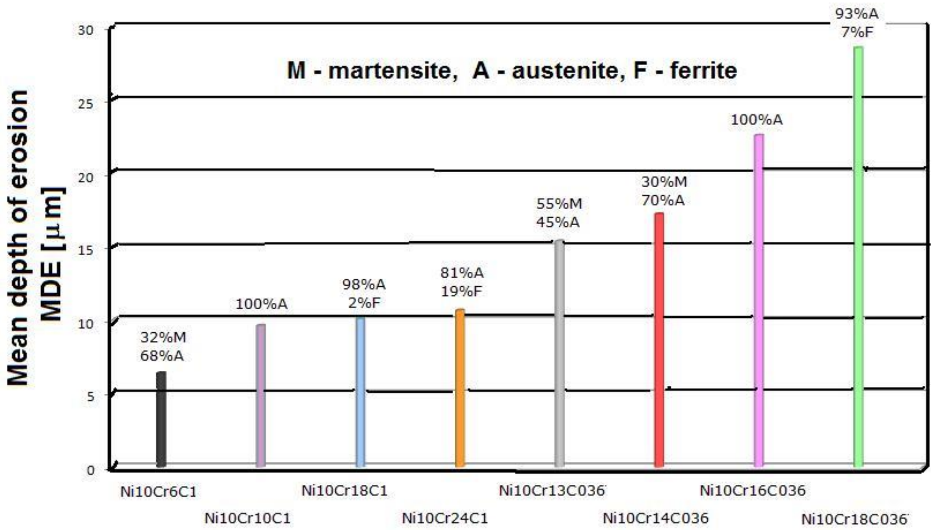


Fig. 3 The influence of microstructure on the mean depth of erosion after 165 minutes of vibratory cavitation attack

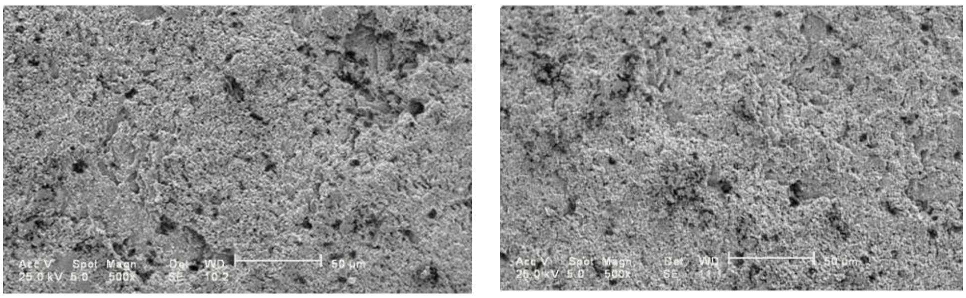
Figure 3 confirms the conclusions drawn from Figure 2 with one exception, namely that the steel with 16% Cr and 0.036% C has a significantly better cavitation behavior/resistance at the end of the cavitation tests compared to the steel with 18% Cr and 0.036% C, according to the parameter MDE. We can see that at the end of the tests, the end of the lowest value of the mean depth of erosion was registered for the steel with 32% martensite and 68% austenite (10% Ni, 6% Cr, 0.1% C). We consider that this behavior is due to the presence of martensite, but also due to the content of carbon (about 0.1%),

The highest mean depth of erosion was registered for the steel with 93% austenite, 7% ferrite and 0.036% C. Moreover, like we saw before at the correlation of the cawitation resistance with the 1/MDER parameter (Figure 2), the steels with 0.036% C have higher MDE values compared to the steels with 0.1% C.

Although in these situations carbon helps to improve the cavitation resistance, we consider that the steels with 0.036% C are a better option for the manufacturing of components for hydraulic pumps and turbines because they are better suited to the frequent welding operations done during routine or major maintenance operations.

Moreover, the data from Figures 2 and 3 confirms the complexity of the mechanical process of cavitation erosion and its dependence on the functional parameters of the installation and also on the microstructure and the mechanical properties of the material.

Figure 4 shows images of the eroded structures taken on the OLYMPUS SYX7 scanning electron microscope for the steels with the highest and the lowest cavitation erosion resistance. The analysis of the Ni10Cr6C1 steel's surface shows a mixed aspect with fine caverns and evenly distributed holes, and a highlighting of the cleavage areas and split grains. The breaks have a fragile aspect.



Steel Ni10Cr6C1 Steel Ni10Cr18C036

Fig. 4 Images of the eroded surface after 165 minutes of cavitation attack – scanning electron microscope (x500)

The surface of steel Ni10Cr18C036 shows big caverns, secondary cracks, cleavage planes and propagation of breaks on slides.

5. CONCLUSIONS

Among the eight studied steels with constant nickel content (about 10%), the highest vibratory cavitation erosion resistance was obtained for the steel with 0.1% carbon content, 6% chromium content and a microsturucture made of 32%martensite and 68% austenite.

The lowest vibratory cavitation erosiosion resistance was recorded for the steel with 0.035% carbon, 18% chromium and a microstructure of 93% austenite and 7% ferrite.

The carbon content affects the cavitation erosion resistance of steels. The steels with 0.036% carbon showed a lower cavitation erosion resistance compared to the steels with 0.1% carbon.

The chromium content has a major effect in establishing the ratios between the microstructural constituents and, automatically, on the steel's mechanical properties and cavitation resistance.

The increase in chromium content leads to lower cavitation resistance for stainless steels due to the expansion of δ ferrite.

The increase of the mechanical properties leads to an improved of steel's cavitation resistance.

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