STAINLESS STEEL COLD-WORK HARDENING THROUGH CAVITATION

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Abstract: Manufacturing hydraulic machinery runners with improved cavitation erosion resistance and in the same time with good welding ability is a great challenge for the specialists in design and maintenance of such devices. A good choice is the use of steels with austenitic structures having in the chemical composition 10% of nickel and 2% to 24% of chromium. Upon these types of steels, in the Cavitation Laboratory of the Timisoara Polytechnic University were undertaken extensive researches. It resulted that the best behavior was obtained with the steels having in the structure both austenite and martensite. For such steels the hardness of the attacked areas receives increased hardness as a result of the implosion of cavitation bubbles.

Key words: stainless steels, cavitation erosion resistance, microstructure, microhardness

1. Introduction

Cavitation erosion and the subsequent repair works remain important problems in running hydraulic power equipments, especially great turbines and pumps [1], [2], [7]. The use of austenitic stainless steel is a favorable solution because its weld ability is very good. When the austenite is unstable its hardness is increased during the implosions of cavitation bubbles [6]. In conformity with Schäffler diagram, such structures can be obtained by maintaining in the chemical composition a constant nickel level and modifying gradually the chromium content. In this way it can be obtained combined structures of austenite plus martensite or ferrite. The austenite plays an important role because it gives good welding abilities and simultaneously offers an improved erosion resistance.

2. Researched materials

The researched steels are employed for manufacturing hydraulic machinery blades or even entire runners as well as for repair works of cavitation eroded zones. The samples from which the specimens were realized were obtained through casting [4], [5]. Before specimen manufacturing, the samples were subjected to specific heat treatments, namely homogenizing annealing followed by a high temperature tempering and a solution quenching with cooling in water or air, depending of the structural constitution [5].
The eight researched steels have reduced carbon content, in order to favor the welding repair works. For obtaining the wanted final chemical composition [5], the prescriptions offered by the Expertise Center for Special Materials (CEMS) of the Bucharest Polytechnic University were used. Because the present work analyzes the effect of cavitation and material structural constitution upon micro hardness, in Table 1 is given the structure constitution established with the Schäffler Diagrame (Fig. 1) for equivalent content of chromium (Cr_e) and nickel (Ni_e) [4].

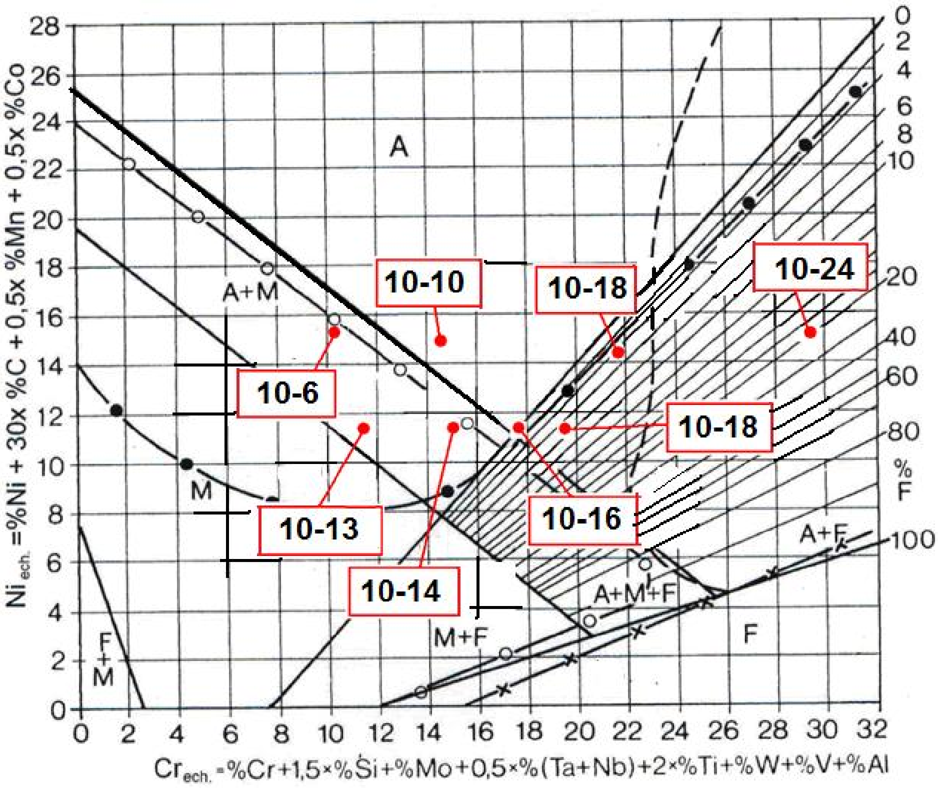

Fig.1. Schäffler Diagram and the positions of the researched steels [2]

Table 1 Microstructural constitution [4]

Steel Symbol (Ni-Cr)	Cr_e [%]	Ni_e [%]		Carbon Content [%]
10-6	11,924	15,173	32%M+68%A	≅1.0
10-10	14,919	14,854	100%A	
10-18	22,414	14,138	98%A+2%F	
10-24	30,362	15,101	81%A+19%F	
10-13	13,209	11,454	55%M+45%A	≅0.036
10-14	15,022	11,4935	30%M+70%A	
10-16	17,824	11,515	100%A	
10-18	19,610	11,508	93%A+7%F	

Note: M-martensite, A-austenite, F-ferrite

The cavitation erosion resistance of the structural constitution was analyzed in [4]. Because the chemical composition of the steels is not a standard one, in the present work the steels were symbolized in a different way that those used in [4], but it easy understandable while it gives the approximate values of the basic chemical elements nickel and chromium.

3. Method and test device

The cavitation erosion tests were effectuated in the T1 cavitation vibratory facility, with nickel tube, in the Cavitation Laboratory of Timisoara Polytechnic University [2]. Even if the device does not respect the ASTM G32-2010 Standard [9], all tests respect the indications of the ASTM Standard. The used liquid was the water from the urban water-supply network at a temperature of 21±1^{0}C.
From the cavitation erosion lost masses, using the relation (1) was determined the mean depth erosion (MDE) and with (2) the mean depth erosion rate (MDER).

$$\text{MDE} = \sum_{i=1}^{12} \left(\frac{4 \cdot \Delta M_i}{\rho \cdot \pi \cdot d_p^2}\right) \text{ [mm]} \quad (1)$$

$$\text{MDER} = \frac{4 \cdot \Delta M_i \cdot 60}{\rho \cdot \pi \cdot d_p^2 \cdot \Delta t_i} \text{ [mm/hours]} \quad (2)$$

where:
ΔM_i - is the mass loss, in the measuring interval "I", in grams,
ρ – is the steel density, in grams/mm^3,
Δt_i – is the exposure time of the measuring inteval „i" in minutes,
i = 1,2, 3...12 – is the measuring interval (for i= 1, Δt = 5 min., for i = 2, Δt= 10 min. and for i= 3...12, Δt= 15 minutes),
d_p –diameter of the area exposed to cavitation (d_p= 14 mm).

The MDER was computed with relation (2) finally were plotted the diagrams MDER (t) (of the type presented in Fig. 1) which allow to determine the parameter 1/MDER$_s$, (where MDER$_s$ is the stabilized value), expressing the cavitation erosion rate resistance.

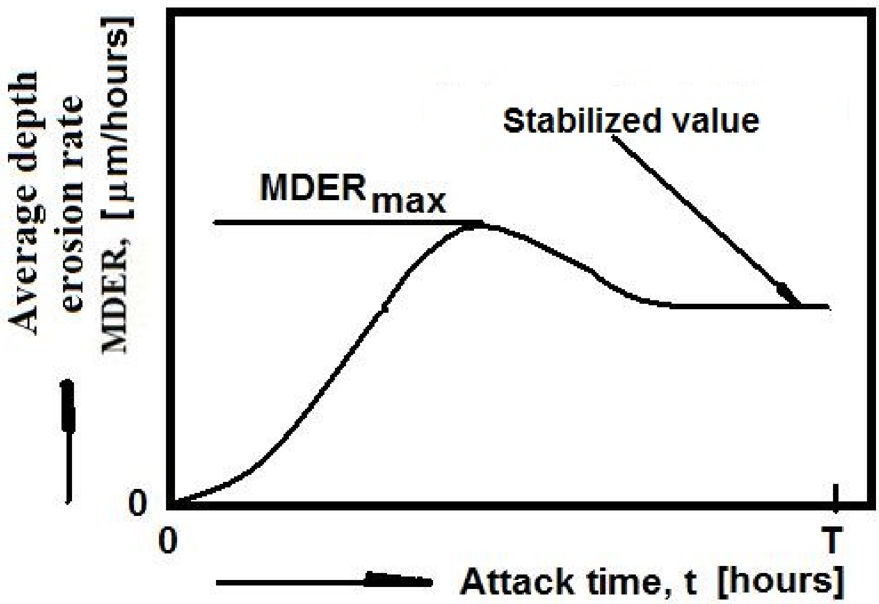

Fig.1 Dependence of mean depth erosion rate against exposure time (qualitative curve)

4. Experimental researches. Discussions

It is known that austenite, especially those labile, during the repetitive impact with the shock waves or the micro jets formed during the implosions of cavitation bubble, is hardened [5], [7], [8]. This hardened thin layer gives an increased erosion resistance to further cavitation implosions [5]. The present work put into evidence the cavitation effect upon the variation of the Vickers hardness (HV), at the end of the 165 minutes of intense cavitation attack and correlates this increased hardness with the parameter 1/MDER which represents the resistance to cavitation erosion.
The Vickers hardness measured in points situated at 1-2 mm distance, Fig. 2, has ±2.3% measurement error and is presented in Table 2.

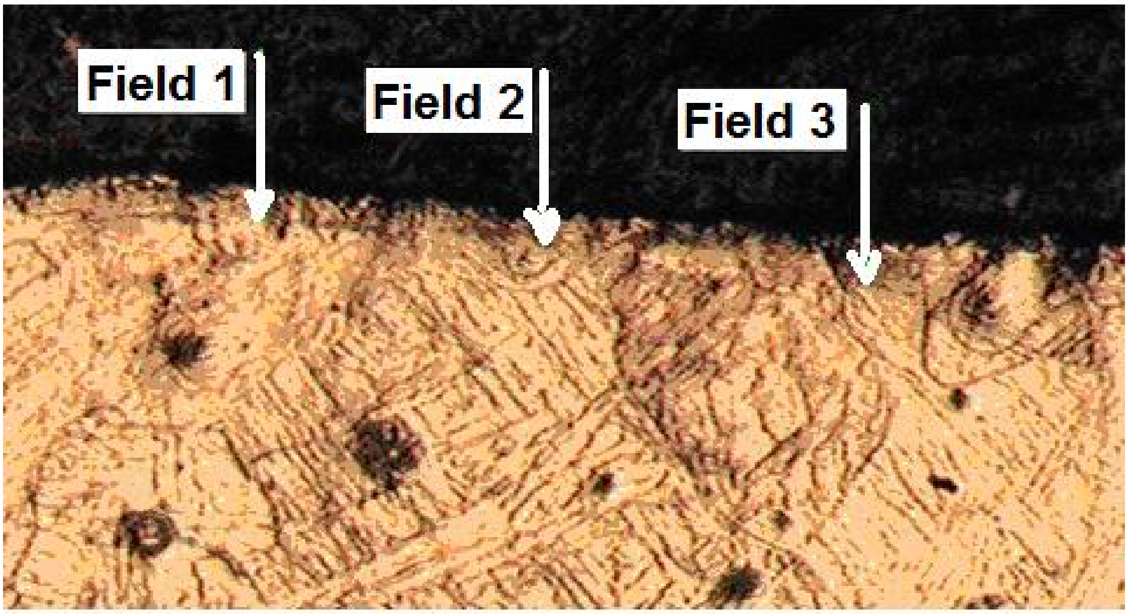

Fig. 2 Vickers micro hardness measurements in the layer adjacent of the surface eroded by cavitation

Table 2 Measured micro hardness

Steel	Hardness HRC	Vickers micro hardness ($\mu HV_{0,1}$)			
		Field 1	Field 2	Field 3	Mean
10-6	48,3	245	256	270	257
10-10	45	230	236	239	235
10-18	38	212	219	214	215
10-24	30	213	209	214	212
10-13	26,5	243	259	269	257
10-14	35.2	256	272	258	262
10-16	30,9	241	232	238	237
10-18	38,3	237	221	226	228

In Fig. 3-5 are presented the variation of mean depth erosion (MDE), mean depth erosion rate (MDER) and cavitation erosion resistance (CER) against the micro hardness measured after 165 minutes of exposure at cavitation. The numbers used in this three pictures correspond to various chemical composition as follows: **1** represent 10-6, **2** represent 10-10, **3** represent 10-18, **4** represent 10-24, **5** represent 10-13, **6** represent 10-14, **7** represent 10-6, **8** represent 10-18.

Each picture contains seven lines, three with great thickness and symbolized A, B, C representing the variation of MDE, MDER and CER against micro hardness and four with slim lines and symbolized I, II, II and IV which contain the materials with approximate the same structure.

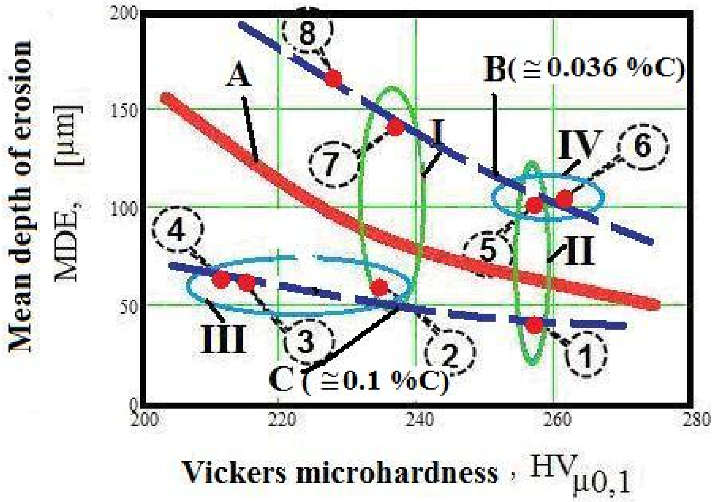

Fig. 3 Mean depth of erosion against micro hardness.

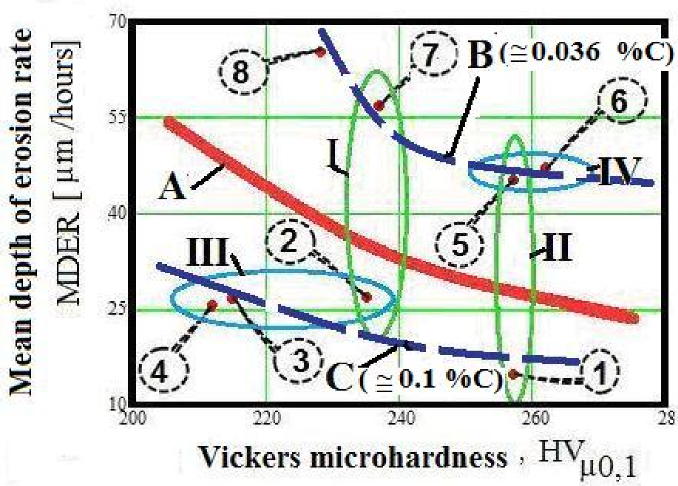

Fig. 4 Mean depth erosion rate against micro hardness

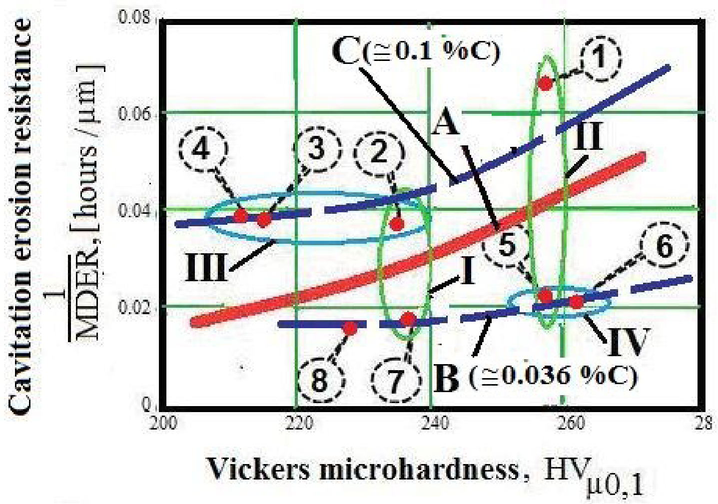

Fig. 5 Cavitation erosion resistance against micro hardness

The lines A show that regardless of the carbon content, when the hardness increases, the mean depth erosion MDE (Fig. 3) and the mean depth erosion rate MDER (Fig. 4) decreases while the

cavitation erosion resistance CER (Fig. 5) increases. This is a characteristic tendency for austenitic structures [3], [7], [8].
The lines B (for steels with a content of 0.036% carbon) and C (for steels with a content of 0.1% carbon) show the important influence of the carbon content upon the hardness. For the steels with a greater content of carbon (line C) the hardness of the attacked layer does not present important increases under the successive cavitation bubble implosions, but even so the erosion resistance is very good.
It can be seen from Table 2 that the hardening phenomenon is accentuated for the steels having in structure both austenite and martensite (the structure with the greatest hardness being martensite).
The laboratory researches show also that there are steels with different hardness (steels 2, 3, 4 marked through the curve III, as well as 5 and 6 marked with the curves IV) with approximate the same cavitation erosion. In the same time there are other steels with the same hardness but with different erosions (steels 2 and 7 marked with curve I as well as the steels 1 and 5 marked with the curve II). These facts can be justified through the different chemical composition and also different structural constituents.

5. Conclusions

As a general feature, the layer subjected to cavitation of the stainless steels present a micro hardness increase as the result of the cavitation bubble implosions.
The existence of austenite (especially the labile one) in the microstructure of steels improves the cavitation erosion resistance, as a result of the cold-work hardening through the repeated implosions of the cavitation bubbles.
The stainless steels with a structure formed by austenite and martensite present a better cavitation erosion resistance in comparison with those having an austenite-ferrite or even a pure austenite structure (the case of the steel with 68% austenite and 32% martensite) as a result of the hardness increase given by the martensite.

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