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Researches upon Cavitation Erosion Behavior of Some Stainless Steels with Different Structures

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Abstract: *The paper is focused on the stainless steel structures and their effect upon the resistance to cavitation erosion. The research was carried out in the Cavitation Laboratory of Timisoara Polytechnic University, on three samples of steel: one with a martensitic structure and the other two samples were duplex steel with structures formed from different proportions of martensite and ferrite (one having 40% martensite and 60% ferrite and the other 76% martensite and 24% ferrite). Those non standard steels were created by SC Prod SRL Bucharest, a company specialized in such matters. The laboratory method used was the standard one, described in ASTM G 32-2010. The laboratory device is of vibratory type, with piezoelectric crystals, having the power of 500 W, double amplitude of 50 μm and a vibration frequency of 2000±100 Hz. The experimental results are presented through characteristic curves, images of the eroded structures and the roughness profiles after cavitation. The experimental results show that martensite is the component, which confers the greatest resistance to cavitation, confirming the technical observations made on the blades and runners of the hydraulic machineries exploited for years in Romania and other countries. The chemical composition, the mechanical properties and the structure are the elements of the steel with the greatest importance upon the behavior with the impact of the micro-jets and shockwaves generated by the implosion of the cavitation bubbles.*

Keywords: *Stainless steels, cavitation erosion resistance, roughness, mechanical properties, microstructure*

1. Introduction

Cavitation, as a destructive hydraulic phenomenon, manifests itself very frequently and uncontrollably in some mechanical devices, especially in the runners of hydraulic machinery (turbines and pumps) and the ship propellers. Such devices must be repaired after 5000 till 12000 hours of running [1] [2]. Their destruction occurs regardless of the employed material. The finding of technical solutions for the reduction of the erosion produced by cavitation forced the scientists to research continuously materials and structures to find the best ones resisting in the same time to a great number of factors (cavitation, corrosion, fatigue strength etc.) The research effectuated in the past by Edel and Palaev [2],[7], Pernik [8] and Orahelasvili [10], on the turbines at CHE V.I Lenin and CHE Timeleansk, show that in spite of the quality of the steel (carbon steel, alloyed steel and stainless steel), cavitation erosion is always present, but in different degrees. It occurs frequently in an unacceptable degree for non-alloyed steel and less for stainless steels, especially for those with a martensitic structure [2], the destruction being dependent on the nature and the percentage of the alloying elements (alpha gens and gamma gens) as well as the main characteristics of mechanic resistance and hardness. The researches effectuated by Popoviciu [6], on the Kaplan turbine at the power plant Iron Gates I (Romania), shows that one and the same material (OH12NDL) has a destruction degree dependent on the intensity of the hydrodynamic flow. This aspect must be taken into account because the hydraulic machine is running at different coefficients of cavitation and even the most eroded area is moving in different places. Therefore, the research regarding the understanding of the mechanism of destruction of the materials through cavitation continues to remain the subject of studies focused on extend life expectancy.

2. Researched Materials

The researched materials are stainless steels. Those were manufactured by SC PROD SRL Bucharest, through genuine receipts, based on studies on the new tendencies of using new stainless steel for manufacturing hydraulic turbines runners and blades.

In Table 1 and 2 are given the chemical composition, the values of the important mechanical characteristics as well as the structures, obtained from the Schäffler diagram, (fig 1) using the equivalent values of chrome (Cr_e) and nickel (Ni_e), computed with specific relations [3], [4], [5]. Because those steels are not standard ones, in the present research the following symbols were used:

Steel I - the stainless steel with the structure formed from 100% martensite (Cr_e = 13.118%; Ni_e = 6.927%)

Steel II - the stainless steel with the structure formed from 40% martensite and 60% ferrite (Cr_e =17.425%; Ni_e = 3.79%)

Steel III - the stainless steel with the structure formed from 76% martensite and 24% ferrite (Cr_e=12.692%; Ni_e=3.152%)

TABLE 1: Chemical composition of the researched steels

Steel Symbol	Chemical composition, %								
	C	Si	Mn	P	S	Cr	Ni	Mo	Fe	Other elements
I	0.03	0.68	0.86	0.05	0.012	12.059	5.597	0.039	rest	
II	0.03	1.57	1.06	0.07	0.013	12.89	1.86	2.18	rest	0.18
III	0.036	0.642	0.204	0.007	0.013	11.96	1.97	0.036	rest	0.29

TABLE 2: Mechanical properties and structure of the researched steels

Steel Symbol	R_m [MPa]	$R_{p0.2}$ [MPa]	Microhardness Vickers ($\mu HV_{0,1}$)	A_5 [%]	Structure
I	1035	725	253	15	100 % M
II	968	678	119	15	40%M+60%F
III	1008	709	189	18	74%M+26%F

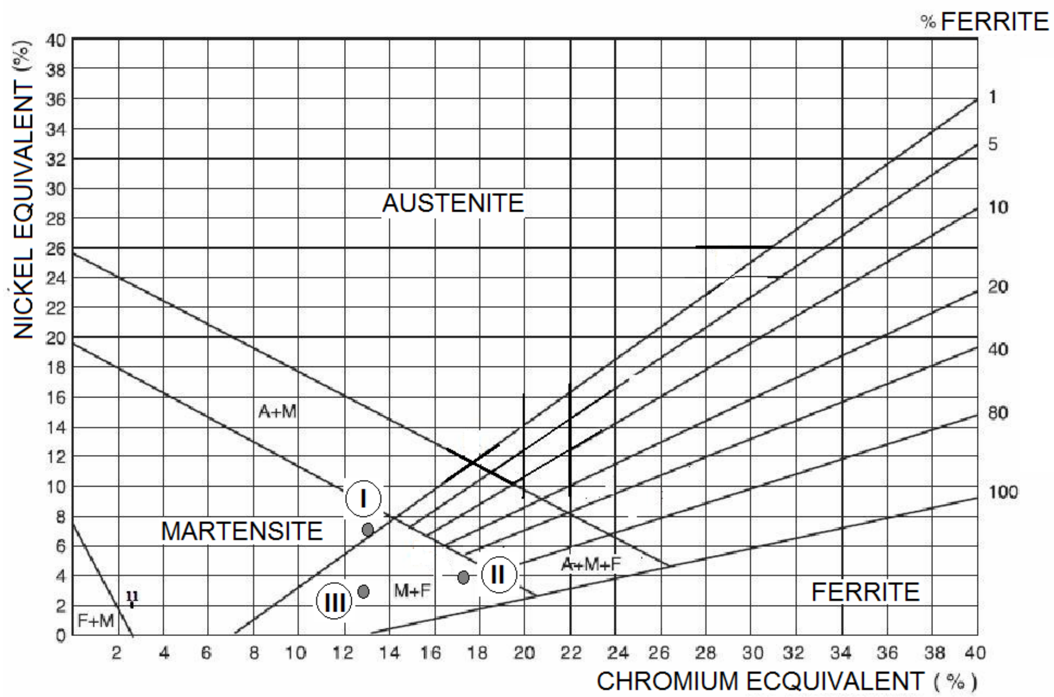


Fig. 1. Position of researched stainless steels on the Schäffler diagram [2]

As it can be seen on the Schäffler diagram, even if the steels have similar chemical compositions (Table 1), the structure is different and Table 2 presents also the differences of the mechanical resistance.
As it results from the present research, those differences determine the resistance to the shock, induced by the impact of the steel with the micro jets and shockwaves, created, during cavitation, by the implosion of the bubbles.

3. The laboratory devices and procedures used for the experimental research

The laboratory device for cavitation erosion is of vibratory type, with piezoelectric crystals, having the following running parameters [9]:
- double amplitude of the vibrations = 50μm
- frequency of the vibrations = 2000±100 Hz
- specimen diameter = 15.8 mm
- power of the ultrasonic electric generator = 500 W
- cavitation liquid: distilled water

The research procedure respect the recommendations of the ASTM 32-2010 Standard [11] some details being those used in the Timisoara Polytechnic Cavitation Laboratory in the past 60 years [5].Those details are: the total exposure to the cavitation attack is 165 minutes, this period is divided into measuring intervals of 5,10 and 15 minutes, the specimen preparation procedure (washing, drying, storage in desiccators), evaluation of the mass loss by material weighing as well as tracking the evolution of the specimen surface (photographic images, periodic analysis under optic and electronic scanning microscopy and measurements of the roughness produced by the erosion).
From every type of steel, in accordance with standard procedure, there have been tested three samples. The experimental curves were constructed by using the arithmetic mean of those values. The experimental results are presented through cavitation erosion characteristic curves such as MDE(t) the evolution in time of the mean depths erosion or MDER(t) the mean depth of the erosion, respecting the ASTM 32-2010 Standard.

4. Experimental Results. Analysis and Discussion

The cavitation erosion evolution during 165 minutes of tests are presented in the specific curves (fig 2 and 3), through pictures of the finally eroded samples surfaces (fig 4-6 and 8) and respectively through the roughness (fig 7), measured in the eroded surface after three radius, randomly chosen. The dispersion of the experimental points around the mean curves, for all three stainless steels tested, in accordance with the literature [2], [4], suggests an increased behavior and resistance to cavitation attack.

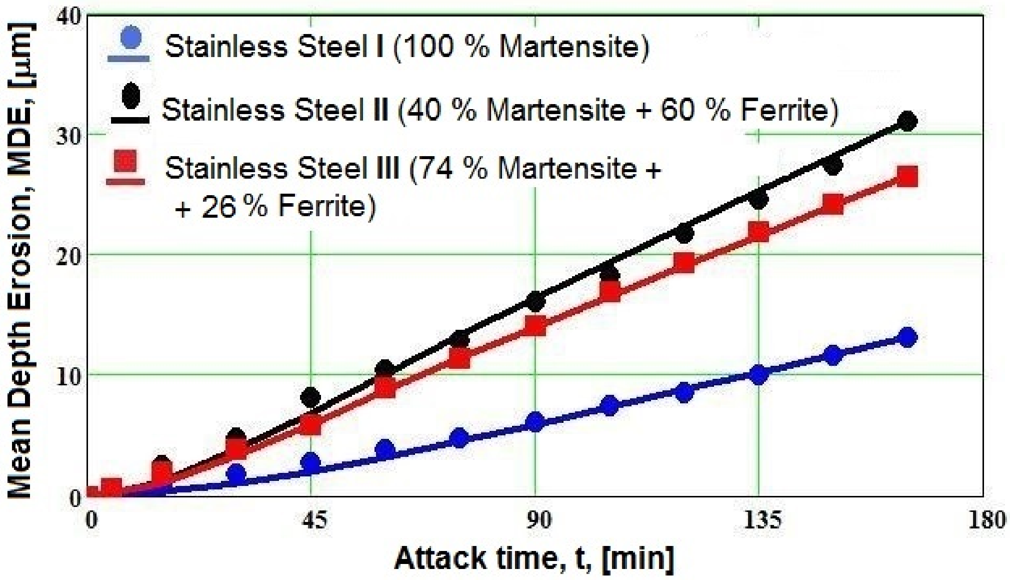


Fig. 2. Mean depth erosion against time

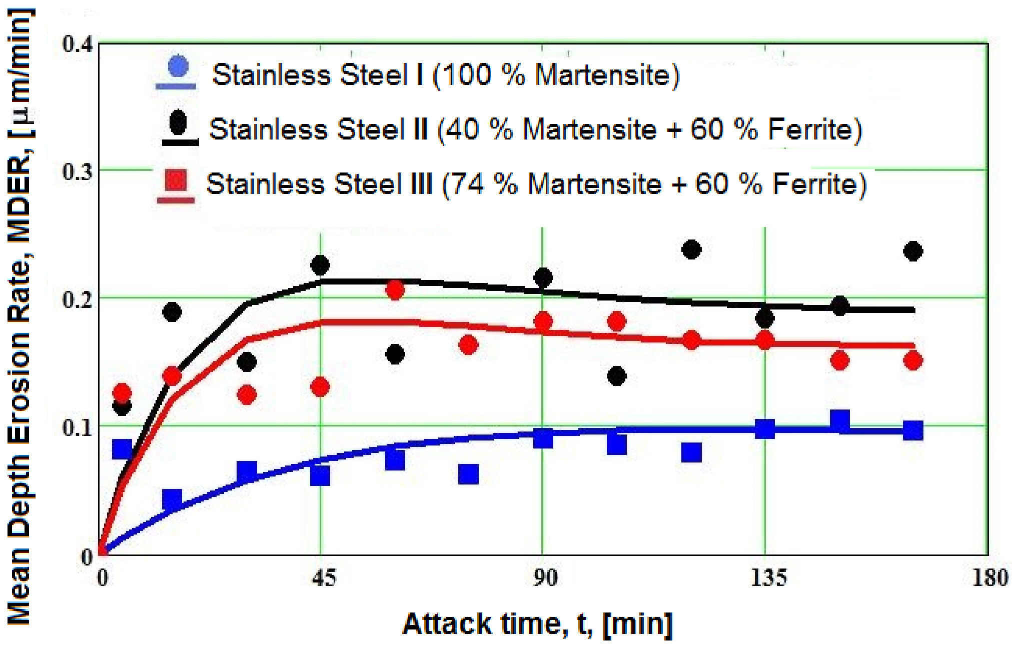
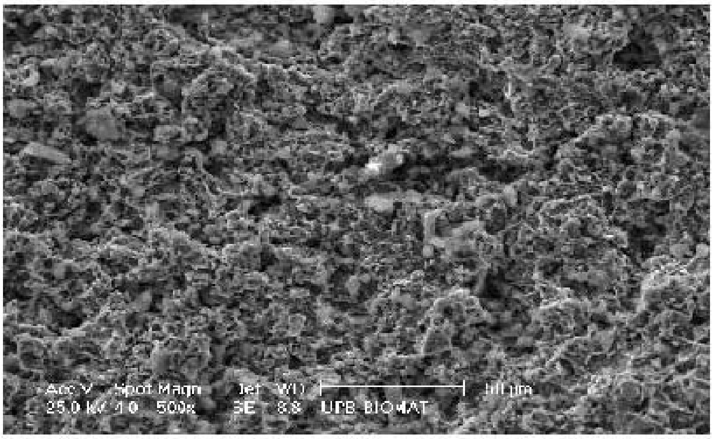
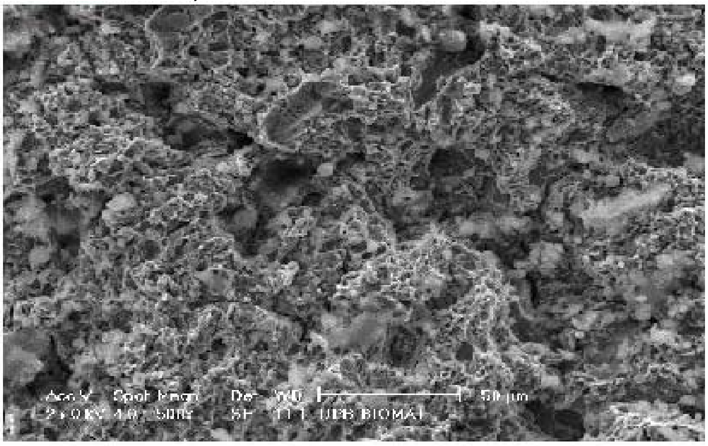


Fig. 3. Mean depth erosion rate against attack time

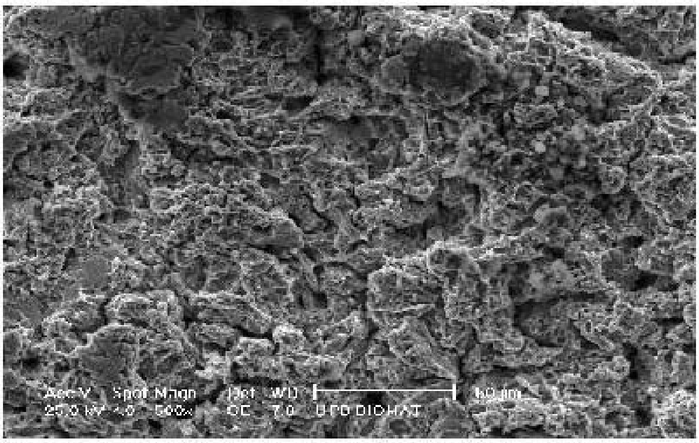
Regardless if the structure is of martensitic type or duplex one (martensite + ferrite) there appear scatter of measured points around the mean curves. This behavior is increased by the quantity of ferrite as can be seen for the steel II which has the greatest degree of scatter (see Fig. 3). These deviations are also a measure of the values for mechanical characteristics (see Table 1). As can be seen in Fig. 3 (curve for steel I) the tendencies of the cavitation erosion rate to remain at the same values at the maximum erosion rates is specific for the materials with great erosion resistance [5] and is a result of the great values of the mechanical characteristics. Taking into account both the slope of MDE(t) curve and the value at which the curve MDER(t) has the tendency to became constant, as is expected, steel I with complete martensitic structure has the biggest cavitation erosion resistance approximate 1.12 greater than those for the steel III (with 74% martensite) and two times greater than steel II (with 40% martensite). Those differences are caused by the presence of ferrite, structural constitutive with weak cavitation resistance properties [2].



a)- Steel **I** (100 % Martensite)



b)- Steel **II** (with 40 % Martensite and 60 % Ferrite)



c)- Steel **III** (with 74 % Martensite and 26 % Ferrite)

Fig. 4. Scanning electron microscopy of the eroded area after 165 minutes of cavitation exposure (x500)

In Fig. 4 are presented pictures of the eroded area taken with scanning electron microscopy. Figs. 5 - 7 are images of the surface degradation of the samples, after 165 minutes of cavitation exposure, registered with a high definition camera (zoomed in 8 times). There are also presented the lines used for roughness measurements. The roughness parameters R_a, R_z and R_t, presented in these pictures have been registered with a MITUTOYO apparatus at the Timisoara National Institute for Research and Development for Welding and Material Testing [9], which has allowed the cartography of the measurement zones (see Fig. 8).

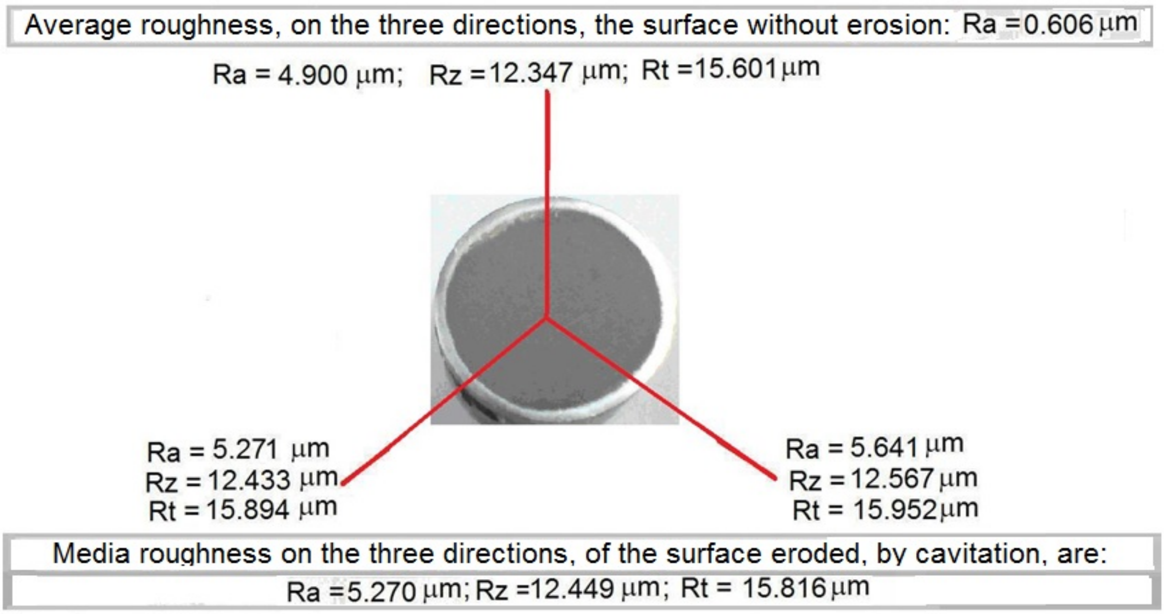


Fig. 5. Roughness for Steel I (100 % Martensite) before and after cavitation exposure

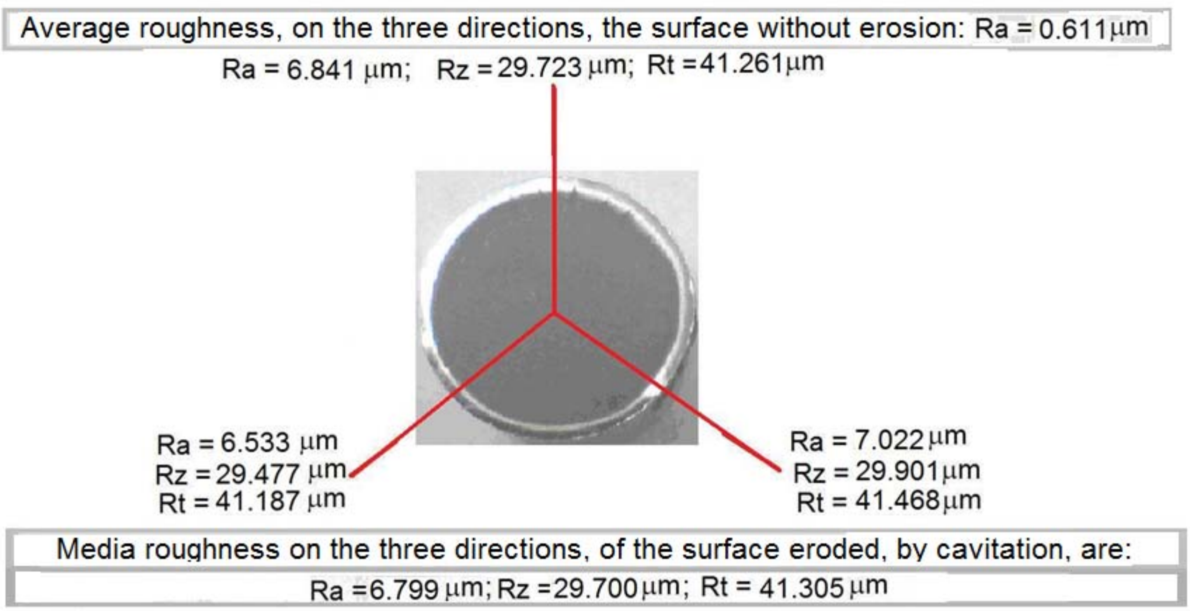


Fig. 6. Roughness for Steel II (with 40 % Martensite and 60 % Ferrite)

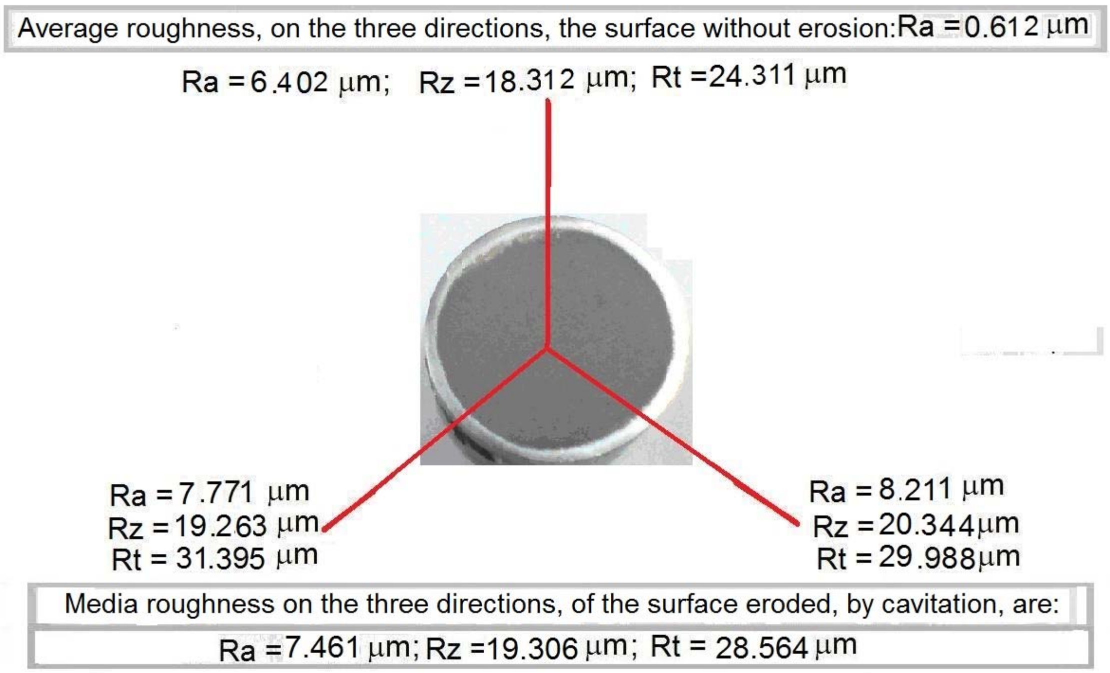


Fig. 7. Roughness for Steel **III** (with 74 % Martensite and 26 % Ferrite)

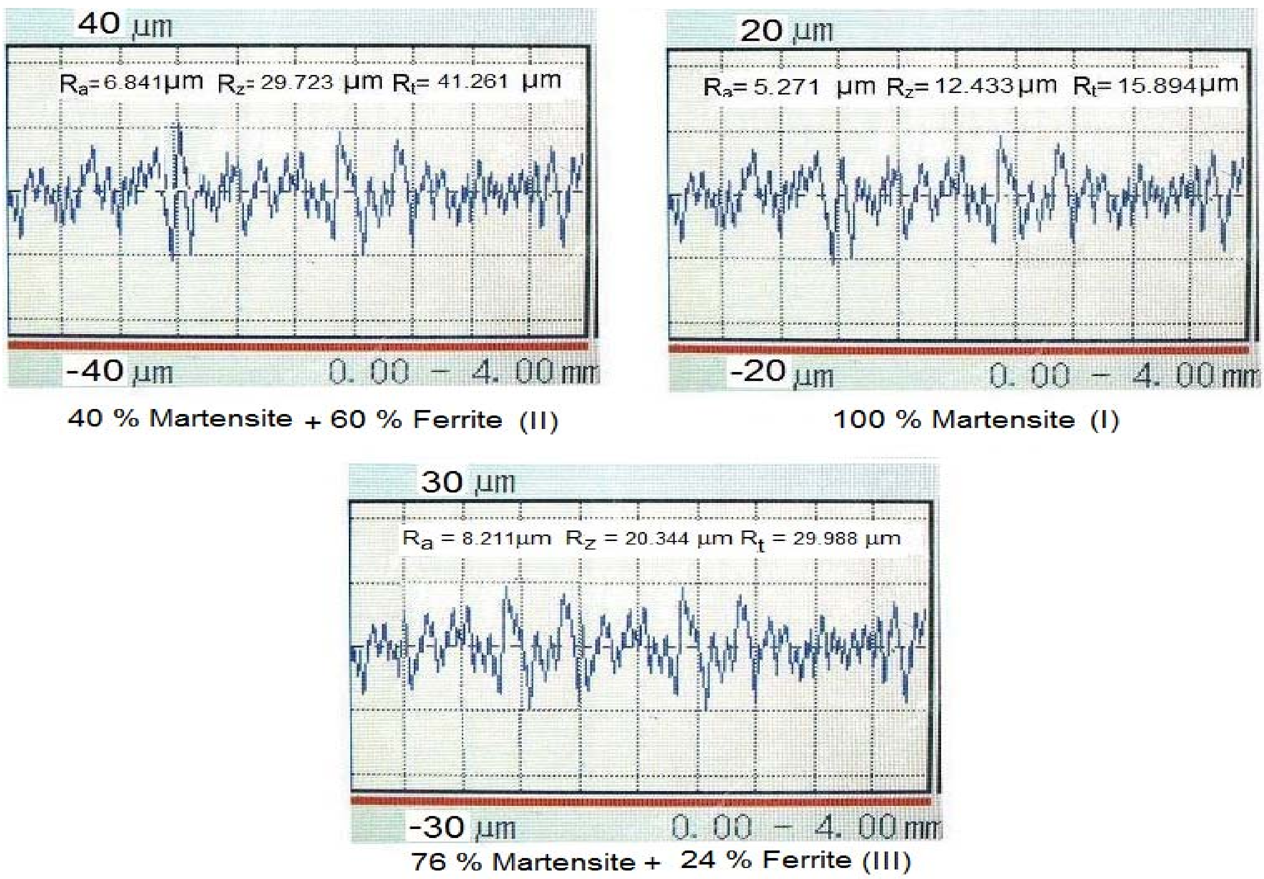


Fig. 8. Roughness before cavitation exposure

The values of the parameters R_a, R_z, R_t from fig. 5-8, reconfirm the increased resistance conferred by the structure with great content of martensite, respectively the progressive decrease of resistance depending on the increase quantity of ferrite.
Figure 9 presents sections with an axial plan (perpendicular on the surface attacked by the cavitation) and the erosion maximum depth value H_{max} which appear in this section. In comparison with the mean depth erosion (MDE) used in Fig. 1, the value H_{max} have differences, especially for steel II (with 60% ferrite). The explanation is given by the small cavitation erosion resistance of the structural component ferrite which gives deep erosions in some particular area and so the value H_{max} differ substantially from the mean depth and is closer to the roughness values measured with the Mitutoyo apparatus. On the contrary, for the steel **I**, with a structure formed exclusively of martensite, the difference between the MDE (at 165 minutes), H_{max} and R_t is very reduced, as a consequence of increased cavitation resistance on this component.

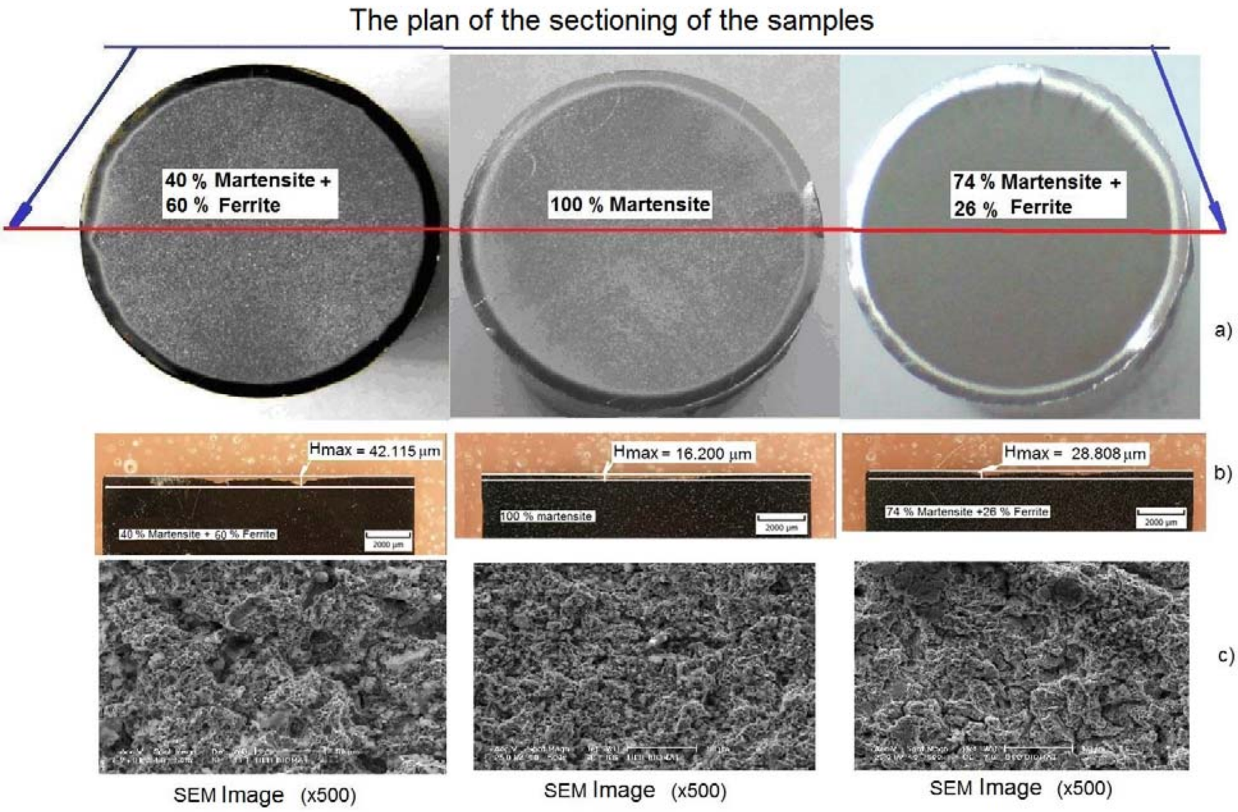


Fig. 9. Aspects of the sectioned specimens: a) the manner in which the specimens were sectioned; b) maximum depth erosion H_{max} after 165 minutes of cavitation exposure in this section

5. Conclusions

The research presented in this paper shows that for the pieces having a constant and heavy exposure to cavitation erosion (such as hydraulic machinery runner or blades) it is preferable to use stainless steels with a great content of martensite in the structural constitution.
In the case of duplex steels, with structures formed from martensite and ferrite, the ones with a smaller quantity of ferrite have the best behavior.
The evaluation of the resistance to cavitation can be also done by measuring the roughness, especially the value R_t, which is enough close to H_{max} (the maximum depth generated by cavitation). Even if the roughness measurements are easier to be done, we do not recommend modifying the prescription of the ASTM 32-2010 Standard which is more reliable.

Acknowledgement

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