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CAVITATION EROSION FOR STAINLESS STEELS HAVING VARIABLE NICKEL CONTENT

Mircea POPOVICIU[1], Ilare BORDEAȘU[2], Victor BALĂȘOIU[2]

Abstract. *The paper present the characteristic cavitation curves obtained in the magnetostrictive facility of Timisoara Hydraulic Machinery Laboratory with four stainless steels having 0.1% C, 12% Cr and variable nickel content. Because nickel is an expensive material it must be kept at a reduced level but with the most favorable characteristics. The result of this study is important for economic manufacturing of those hydraulic turbines parts subjected to cavitation erosions. The optimum nickel content was found to be around 5%. In the future the interval (4.5…6)% must be more attentively tested. No heat treatment was applied because in the present research only the influence of chemical composition was studied.*

Keywords: cavitation erosion, cracks, chemical composition of stainless steels

1. Introduction

The lower limit of the pressure in a hydrodynamic flow is the value of the saturated vapours pressure, at the working temperature. If in a point of the liquid stream the pressure reaches this limit, in this point occur a bubble filled with vapours and dissolved gasses (a cavity). Carried away by the flow, when the cavities reach a zone with increased pressure they suddenly disappeared. This phenomenon is called "cavitation" and can be defined as the process of formation and disappearing of bubbles in a liquid as a result of pressure decrease under a critical limit. Cavitation is a phenomenon similar to boiling. The difference consists in the fact that boiling is produced by heat supply while cavitation by pressure reduction.

The presence of cavitation in a hydraulic device generates three undesirable effects: noises and vibrations, drastic reduction of efficiency and strong erosions of the solid walls which, guides the flow. There are also other fields of human activities in which, cavitation is used as a working process. In medicine it is used for breaking into small pieces the kidney stones [1]; in environment protection for destruction of plankton in lakes, ponds and see [2]; in shipyards for peeling off old painted surfaces [3].

With an improved manufacturing process of hydraulic devices (hydraulic turbines, pumps etc.) the erosion reduction can be reduced, in certain limits

[1]Prof., PhD, full member of the Academy Romanian Scientists, mpopoviciu@gmail.com.
[2]Prof., PhD, Eng., Mechanical Engineering Faculty, Chair of Hydraulic Machinery, University "Politehnica" of Timisoara, Romania.

of cavitation intensity, by using materials with special properties, for example stainless steels with Chromium and Nickel. The need for new technological solutions, with the purpose to increase the life of the elements running in cavitation conditions, especially hydraulic turbines, forced the researchers to direct their studies both on the erosion phenomenon itself and also on the phenomena produced inward the material structure during the bubbles implosion. Both direction encounter great difficulties. The bubble implosion can generate shock waves as well as high velocity jets [4,5]. The erosion intensity can be influenced also by chemical and thermal processes. The study of the processes inward the materials encounters also great difficulties as a result of the multitude of factors which influence the erosion: chemical constitution, structure, the manufacturing procedure of the element, the heat treatments etc.

In the present paper is analyzed, with a laboratory facility, the effect of the nickel content upon high-alloyed stainless steels.

2. Tested Materials

In order to undertake the laboratory researches, at S.C. PROD SRL Bucharest there have been realized by casting four stainless steel cylinders with constant contents of carbon and chromium and variable contents of nickel. After discussions with the metallurgical specialists from S.C. PROD SRL Bucharest (factory specialized in stainless steel casting) and from a Special Materials Expertise Center of Bucharest “Politehnica” University it was taken the decision to have pieces with approximately 0.1% C and 12% Cr and the nickel content to be approximately: 0%, 2%, 6% and 10%. These four samples were named after the content of chromium and nickel: 12/0; 12/2, 12/6 and 12/10.

Table 1. Echivalent Ni and Cr content and microstructure in %

	Equivalent content		*Microstructure*		
Steel	$(Ni)_{eq}\%$	$(Cr)_{eq}\%$	*M*	*F*	*A*
12/0	4.81	14.2685	75	25	0
12/2	6.25	14.626	70	30	0
12/6	10.15	14.9	40	0	60
12/10	14.74	14.6685	100	0	0

The four samples were cylinders with the diameter of 80 mm and the length of 170 mm. The specimens for the mechanical, chemical and cavitation erosion characteristics were manufactured from those cylinders. No heat treatment was applied. The microstructure was established from the Shäfler diagram, on the ground of the equivalent chromium and nickel content [6, 7]. Table 1 presents the equivalent contents of nickel and chromium and the microstructure of the four steels used in cavitation tests, in percentage of martensite, ferrite and austenite. The detailed chemical composition of the used steel was obtained in the Research Center CESM of the Bucharest Polytechnic University together with the hardness and is presented below.

Steel 12/2: 0.114% C; 12.02% Cr; 2.15% Ni; 1.36% Mn; 1.35% Si; 0.05% Mo; 0.025% W; 0.097% V; 0.257% Ti; 0.034% Nb; 81.7% Fe and the rest acompanying elements; hardness 40 HRC; **ρ=7.751 Kg/dm^3**

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Steel 12/10: 0.105% C; 12.02% Cr; 10.28% Ni; 2.62% Mn; 1.72% Si; 0.037% Mo; 0.007% W; 0.043% V; 0.017% Ti; 0.04% Nb; 72.1% Fe and the rest accompanying elements; hardness 25 HRC; **ρ=7.826 Kg/dm^3**

The hardness has certain importance for cavitation erosion and is influenced by the content of martensite. For the steel 12/6 the great quantity of martensite together with the alloyed austenite determines an increase of the hardness. The structure is that resulted from casting. No heat treatment was applied because we want to study in the present research only the influence of chemical composition. In following researches there will be studied also the influence of various heat treatment.

3. Cavitation Test Method

In order to obtain cavitation erosions the vibratory facility of the Timisoara Hydraulic Machinery Laboratory was used. The vibratory facility is recommended

Table 2. Comparison of main characterisitcs

Characterisitc	*MU*	*T 1*	*G-32*
Frequency f	kHZ	7±0.5	20±0.5
Amplitude A	µm	47	50±5%
Electric Power P_{el}	W	500	250…1000
Immersion depth	Mm	6	12±4
Volume	mL	1500	1000
Diameter	mm	150	100±15
Liquid depth	mm	150	100±10
Liquid used		Distilled water	Distilled water
Liquid temperature	ºC	20±1	25

by the ASTM Standards [8] and is accepted by a great part of the researchers working in the field. The test facility of Timisoara Hydraulic Machinery Laboratory was built before the world wide introduction of the ASTM Standard. With this facility there have been tested numerous materials used for industrial purposes.

Because our facility does not respect the ASTM Standard, in Table 2 there are presented the main characteristics of our test facility (T1) and those recommended by ASME (G-32). The greatest differences are the values of the vibration amplitude and frequency as well as the immersion depth. In the past, using our facility, there have been obtained good correspondence between the laboratory results and the behavior, in industrial practice, of the tested materials.

4. Experimental results

The treatment of the experimental results was effected using all the indications given in the G- 32 Standard. The cavitation erosion intensity was established using as primary index the recommended “total cumulative depth of erosion in μm” obtained by converting, at first, the mass losses (directly measured in mg during the tests) in volumes and after that dividing the results with the working area of the specimen [8]. The time dependence of cavitation erosion is presented in Figure 1. The linear approximation of the experimental points is quite good and

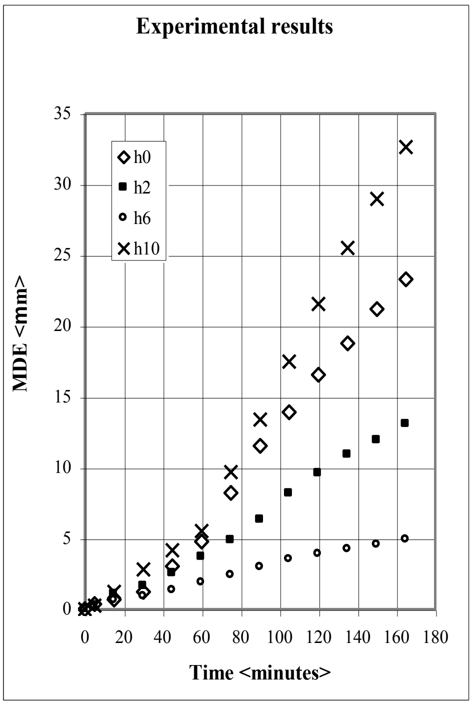

Fig. 1. Time depend. of cavitation erosion.

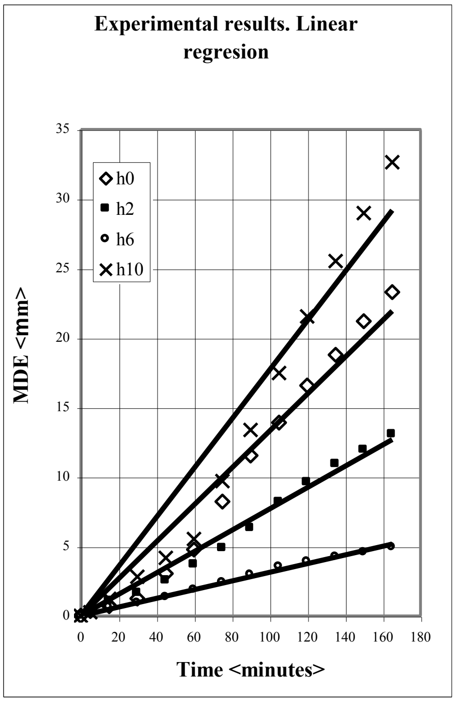

Fig. 2 Linear approx. of experimental points.

can be used for industrial purposes (the square value of the correlation coefficient oscillates between 0.94394 and 0.99427). The approximation can be seen in Figure 2. If we select for approximation a 4th degree polynomial the same coefficient varies between 0.99914 and 0.99824 and the approximation can be seen in Figure 3.

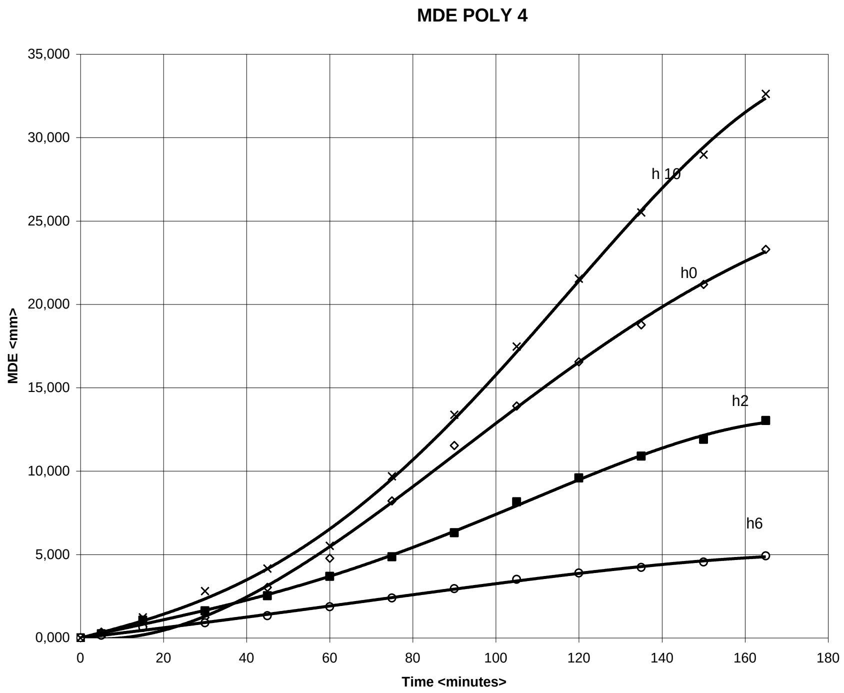

Fig. 3 Approximation of experimental points with a **4th degree polynomial**

Table 3. Regression Equations

Spec.	*Equation*	R^2
Linear regression		
h0	1.3286E-01x	9.5858E-01
h2	7.6836E-01x	9.8399E-01
h6	3.1211E-01x	9.9427E-01
h10	1.7690E-01x	9.4394E-01
Regression with a 4th degree polynomial		
h0	$1.6602.10^{-8}.\ x^4-1.2585.10^{-5}\ .x^3+2.6239.10^{-3}x^2-2.4520.10^{-2}.x$	9.9841E-01
h2	$-2.8057.10^{-8}.\ x^4-6.7525.10^{-6}\ .x^3+2.1772.10^{-4}\ .x^2+5.6391.10^{-2}.x$	9.9914E-01
h6	$-2.4246.10^{-9}.\ x^4-1.9864.10^{--7}\ .x^3+3.1431.10^{-5}\ .x^2-2.9797.10^{-2}.x$	9.9824E-01
h10	$-6.5359.10^{-8}.\ x^4-1.5251.10^{-5}\ .x^3+6.1534.10^{-5}\ .x^2-6.4357.10^{-2}.x$	9.9889E-01

The regression equations are given in Table 3 together with the square value of the regression coefficient (we use this value because it is automatically computed in the Microsoft Excel program).

Evidently, the polynomial regressions approximate better the experimental results in comparison with the linear one.

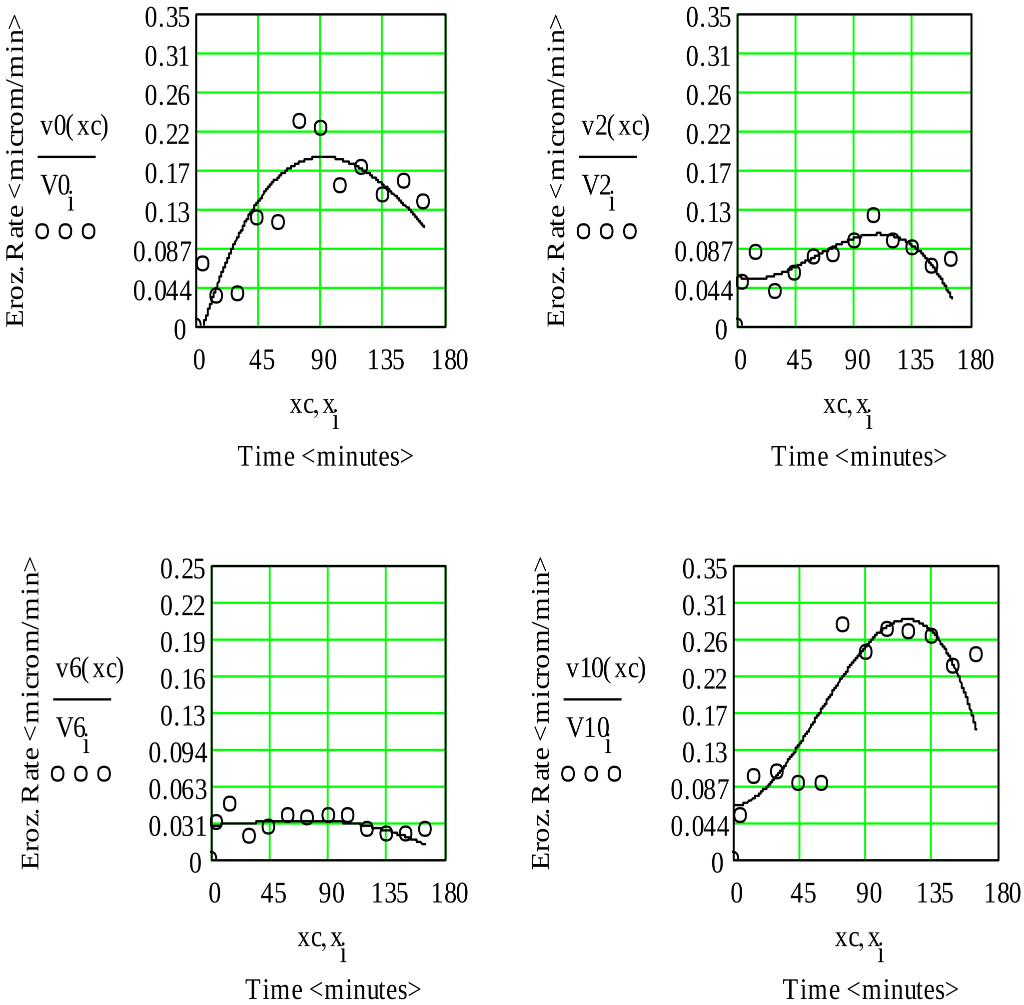

Fig. 4. Cavitation erosion rates.

Using the fourth degree polynomial (presented in Table 2) and the Mathcad program there have been computed the velocities and acceleration equations, by employing the first and second derivatives.

In the Figures 4 there are presented both the experimental results and the approximations curves of the equations obtained in the described manner.

Fig. 5 Aspects of the eroded specimens.

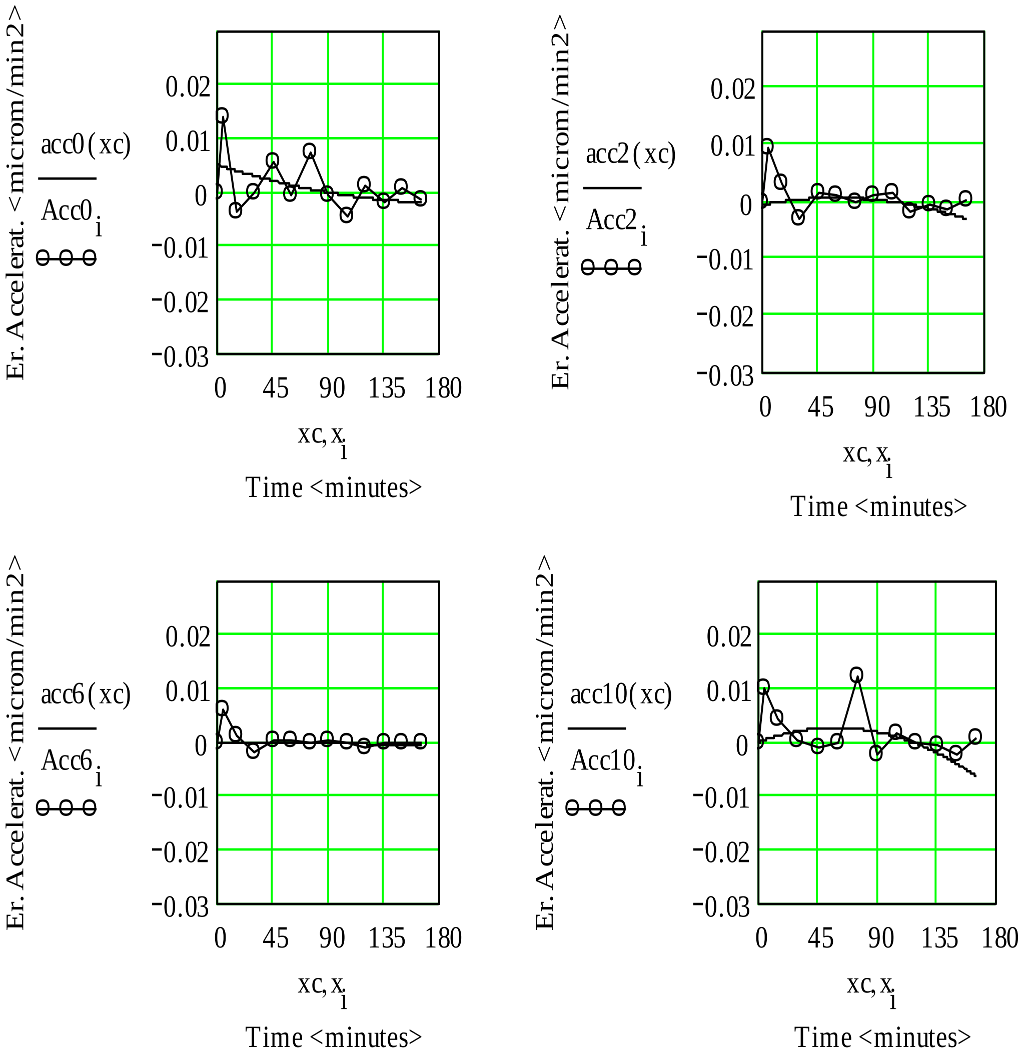

Fig. 6. Cavitation erosion accelerations.

Evidently, there is possible to obtain the approximation curves directly from the velocities and the accelerations computed from the measured points.

Nevertheless we consider that the velocity and acceleration curves must correspond with the previous obtained equation for the total cumulative depth of erosion.

From the velocity curves, as in other researches [9], it is very difficult to obtain conclusions about the evolution of the erosion process. From the acceleration curves [10], it became clear that in the first 90 minutes of attack the erosion has an erratic behavior, especially for materials with reduced resistance to cavitation erosion. From this point of view the linear approximation of the MDE curves is enough consistent. With the linear approximation, the erosion acceleration curves result as a straight line superposed with the abscissa. In reality the acceleration

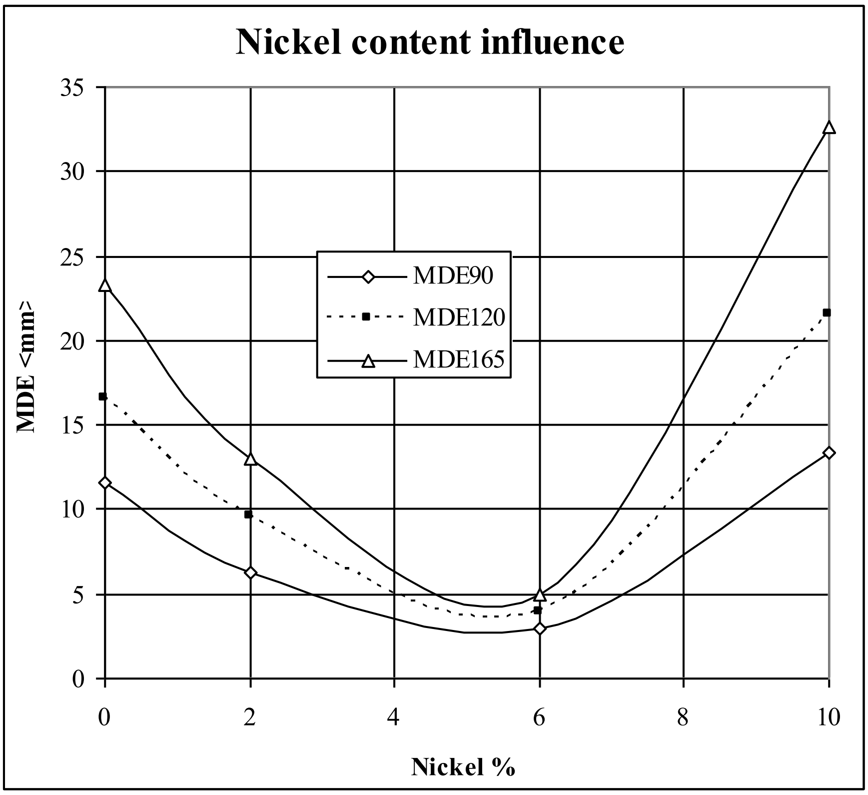

Fig. 7 The influence of the nickel content upon the cavitation resistance

oscillates around the abscissa, at the beginning with increased amplitudes, but after 90 minutes the amplitude decreases especially for materials with high resistance. The use of the polynomial regression does not add important information (in other words it can be considered that the linear equation for the cumulative mean depth erosion against time can be considered as a valuable approximation. The oscillation of cavitation erosions accelerations around the mean value is very great for materials with low resistance (12/0 and 12/10), decreases when this quality is improved (12/2) and becomes minimum for the material with the best quality (12/6).

From Figure 7 it results that the optimum percentage of nickel in the steel is around 5.5%. In the future, the interval of nickel content between 4 and 8% must be more attentively studied in order to obtain, with increased precision, the optimum nickel value.

For the future researches we strongly recommend selecting samples with variable nickel content around 5.5% (perhaps between 4% and 7%), in order to obtain with increased precision the value of the optimum content. It is also advisable to reduce the carbon content at values around 0.05%. With such a carbon content is possible to obtain small decreases of the cavitation erosion but the welding repair works will become easier**.**

Conclusions

1. The experimental researches reveal an optimum nickel content around 5.5%. In the future the interval (4.5 … 6) % must be more attentively tested, in order to obtain more precise values.
2. The evaluation of the material behavior through the variation in time of the mean deep erosion, compulsory requested by the standard G-32 is easy to be obtained.
3. The evaluation through the erosion velocity (not compulsory requested by the Standard G-32) is extremely difficult because the great dispersion of the experimental points.
4. If the evaluation through the acceleration erosion versus time is adopted the resulted curves are more easy to be interpreted. For these results, the linear approximation of the points, in the system mean deep erosion versus time is a good solution. Evidently, the erosion acceleration does not remain zero but oscillates around the abscissa. The use of better approximations for the acceleration curves does not add valuable information in the erosion acceleration curves.
5. In the future these researches must be completed with others regarding the structure influence, obtained by various heath treatments. A proper heat treatment will increase the cavitation erosion resistance.

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