Considerations Regarding the Behavior to Cavitation Erosion of Two Carbon Alloy Stainless Steels Used in the Manufacturing of Hydraulic Equipment Drawers of Command, Adjustment and Distribution

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Abstract: *The performances of hydraulically driven systems are dependent on the developed forces and execution speed. However, increasing the speed of execution makes that inside of the command, adjustment and distribution equipment, when using low viscosity fluids, to appear hidromatic phenoms of the cavitation type. Modern methods of flow modeling shows that the areas where pressure oscillations leads to the appearence of cavitation, are the flow slots created between the mobile elements (drawers) and body/seat of the hydraulic equipment. Although the literature contains more information about the behavior/cavitation resistance of materials of components that run within the range of cavitation, an investigation of their behavior to cavitation erosion is required. Filling the data with cavitation erosion elements is beneficial, since it occurs simultaneously with cavitation erosion and abrasive erosion, cumulative effects that can affect the performance and work accuracy of the equipment. Therefore, this paper contains the result of research and analysis of the behavior to vibratory erosion of two low alloy steels (16MnCr5 and 34CrNiMo6), in annealed condition, used in the manufacturing of mobile elements of hydraulic equipment. Qualitative assessment of resistance to cavitation is done by comparing the carbon steel alloy 41Cr4, standard in the cavitation laboratory of the Polytechnic University of Timisoara, for steels in this category. The comparison based on curves and cavitation erosion specific parameters show that the investigated steels have lower resistance to the standard, but can be improved by applying surface hardening technologies and increasing the mechanical properties of the surface exposed to cavitation.*

Keywords: *cavitation erosion, carbon steel alloy, cavitation resistance, mechanical properties, chemical composition, average penetration depth of erosion, erosion rate, cumulative erosion rate*

1. Introduction

The speciality literature presents the cavitation as a complex hydrodynamic phenomena, specific to the flowing of liquids, which is manifested by reducing the energy and functional parameters, the appearance of noises and vibrations, and worst of all, by erosion of solid borders which guide the flow [1], [5].
How the phenomenon can only be diminished, hydromechanical equipment, which is always present, will work, almost always in the so-called ”industrial admitted cavitation”, that cost in maintaining the current energy parameters, low level noise and vibration and acceptable cavitation erosion, requiring repairs and replacements of equipment after long periods of operation.
Most cavitation erosion studies are made on hydraulic machines, pumps and marine propellers,

because they are the most affected and involves high costs of manufacturing and repairing [9].
From the bibliographic documentation [1], [2], [3], [4] results that the hydraulic equipment from the actuating schemes are, also, subject to cavitation, with all it's effects.
Observations made at the current and maintenance works, on the crossing zone between drawers and command equipment slots, distribution and control, as well as numerical modeling, have highlighted cavitational and abrasive erosions of drawer shoulders and equipment bodies.
Therefore, the performance of the equipment is subject to the judicious selection of the material, respectively of the application of heat treatments, thermo-chemical and mechanical for the increase of their resistance to the distructive effects of cavitation erosion, taking into account the economic effects of such measures [6], [9].
So, along with the basic problem concerning a compromise between the mechanical strength and plasticity characteristics, the cavitation erosion behavior must also be studied.
The research accomplished in this paper provides important data on cavitation erosion behavior of two low alloy carbon steels *(16MnCr5 and 34CrNiMo6 in annealed condition)*, commonly used at manufacturing of mobile elements of the hydraulic systems equipment [10].

2. Research material. Apparatus and research method

From the analysis of the hydraulic equipment manufacturers, coupled with the analysys of the properties of materials and supply costs of materials [2], [7], from which these elements are made, results the fact that the most suitable for the hydraulic equipment drawers, are the low alloy steels.
To investigate the effects of cavitation erosion, there were chosen two alloy steels 16MnCr5 and 34CrNiMo6, used in the manufacturing of control device drawers, distribution and control of hydraulic system actuators.
The chemical compositions of the two steels (according to the quality certificate released by S.C. MECHEL-TARGOVISTE S.A., Romania) are displayed in Table 1, and the values of the main mechanical characteristics, determined in the Strength of Materials laboratory of the Polytechnic University of Timisoara, are summarized in Table 2.
In Tables 1 and 2 are given the chemical composition and values of the mechanical properties of the 41Cr4 steel, standard for alloy steels and used in the manufacturing of hydraulic equipment components exposed to the cavitation erosion [2].

TABLE 1: Chemical composition of the examined steel

Brand	Accompanying and alloying elements, %										
	C	Si	Mn	Cr	S	P	Al	Ti	Mo	Cu	Ni
16MnCr5	0,21	0,32	0,97	1,00	0,03	0,09	0,0175	0,035	0,018	0,2	0,1
34CrNiMo6	0.34	0.25	0.50	1.5	0.035	0.025	-	-	0.25		1.55
41Cr4	0.42	0.25	0.70	1.05	0.03	0.025	-	-	-	-	-

The mechanical characteristics, determined in Strength of Materials laboratory of the Polytechnic University of Timisoara, have the values shown in Table 2.

TABLE 2: Mechanical characteristics

Material	Rm N/mm^2	Rp0,2 N/mm^2	A5% %	Z% %	HB daN/mm^2	Bibliography
16MnCr5	1174	1059	12	51	207	[12]
34CrNiMo6	1200	900	10	45	250	[13]
41Cr4	1000	660	12	35	255	[2], [14]

The researches have been accomplished in the Cavitation laboratory of the Polytechnic University of Timisoara, on the performant crystal piezoelectric vibrator device, with modern facilities, that ensures process control and computer management, accomplished by international standards ASTM G32-2010 [11].
The functional parameters of the device, kept constant throughout the whole research duration, are: power 500 W, vibration frequency 20000 $\pm$ 2% Hz, amplitude of vibration 50 μm, sample diameter 15,9 ± 0,05 mm, supply voltage 220 V/50 Hz, working fluid double distillated, working fluid temperature 22±1ºC [4], [8].
In accordance with the requirements of the standards ASTM G 32-2010, the search procedure [2], [6], [10], from both steels were exposed three samples to cavitation erosion. The total duration of the cavitation attack, according to custom laboratory is 165 minutes, divided into a period of 5 and 10 minutes and 10 of 15 minutes each.
In the diagrams contained in the paper, the analysis underlying the cavitation behavior, are shown the curves obtained from the mediation of experimental results recorded on the three samples.

3. Experimental results. Analysis and discussions

In Figures 1 and 2 are presented measured values for the eroded mass and the corresponding velocity, of different periods of attack.
The mass of material, lost by the sample through cavitation erosion, was obtained by weighing the analytical balance type Zatklady, which allows the reading of five decimals places. To assess the distant mass, the reading was performed at the beginning and end of the final period of attack ; between periods, the samples were stored in a dessicator, in order to avoid oxidation affecting real loss by cavitation erosion.
Erosion rates, expressed in points, corresponding to the 12 periods of attack, were calculated according to the ratio:

$$v_i = \Delta M_i / \Delta t_i \qquad (1)$$

where Δm- represents the mass of material lost through cavitation erosion in the period Δt
Δt – represents the duration of the **"i"** period of attack (of 5, 10 and 15 minutes)

In Figure 1 are shown images of degredation produced by the vibratory cavitation in the 165 minute attack. Images of the eroded structure are recorded at the scanning electron microscope (magnification of 2500 x), and the degraded surfaces of the samples were photographed with the photo camera, at a magnification of 8 x.

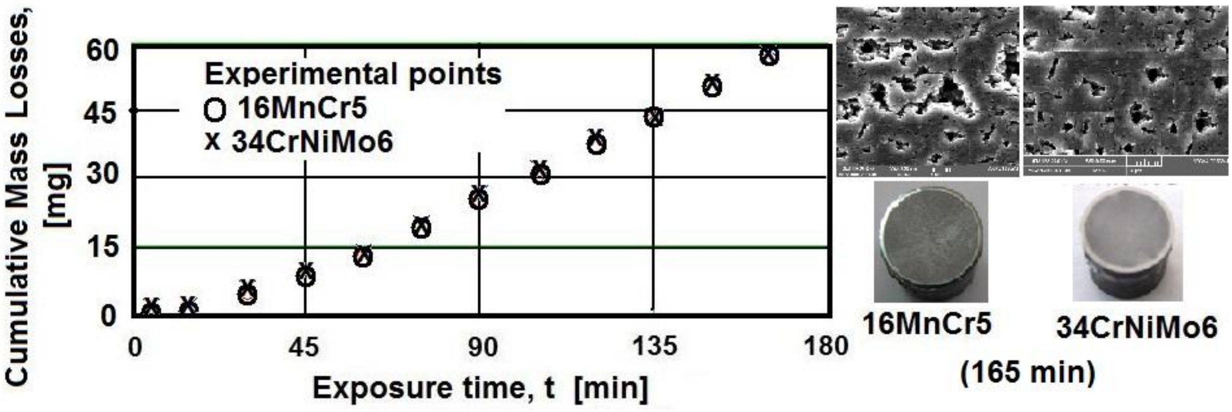

Fig. 1. Evolution of the weigh loss (cumulative) with the duration of the cavitation attack

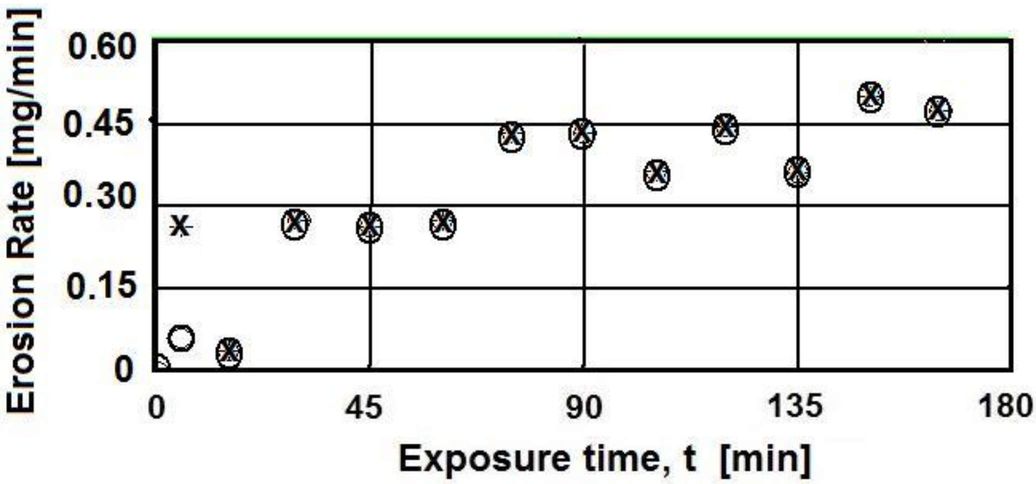

Fig. 2. Dispersion of the erosion rates during the periods of cavitation attack

The developments of the experimental points (1 and 2), show that the two steels, in the annealed condition, behave identically to the erosion generated by the vibratory cavitation. This kind of behavior, rare met, even in materials from the same quality class (as in the case of the two steels), shows the cumulative influence of all factors that determine the type of material (chemical constitution, respectively structure type, level of the mechanical properties).The only behavior difference is the one of the 5 minute period, in which the 34CrNiMo6 steel leaves the impression that it has greater losses (the phenomenon is very well visible in Figure 2). Our experience and all researches show that the losses from the first 15 minutes are not a real reflection of the sample mass loss by cavitation. They are strongly influenced by the abrasive dust and the tip of the roughness, remaining after processing the surface exposed to the attack, regardless the washing type before subjecting to the test [2]. Also, images of the degraded surface and of the cavitated microstructure, attached to the diagram of mass loss (Figure 1), are a confirmation of the identity of the two steels throughout the whole duration of the attack. The caverns left after the expulsion of grains and the level of pitting, highlighted by the pictures taken with the scanning electron microscope shows that in the annealed condition, the two steels (16MnCr5 and 34CrNiMo6) have the same resistance to cavitation erosion generated by the vibrator unit of the Polytechnic University of Timisoara’s laboratory. Given that the device is accomplished by the ASTM G32-2010 standards, we estimate that even in the testing conditions at cavity vibration generated by the devices with different functional parameters (electric power, amplitude and frequency of vibration) the behavior would be similar to the one recorded by us.
In Figure 3 are shown the mean depth losses cumulated by the penetration of erosion and in Figure 4 penetration rates of erosion. The two parameters were calculated using the equation (2):

-mean depth erosion (MDE), corresponding to a period of attack:

$$\mathrm{MDE_i} = \frac{4 \cdot M_i}{\rho \cdot \pi \cdot d_p^2} \ [\mathrm{mm}] \tag{2}$$

respectively the cumulative one

$$\mathrm{MDE_i} = \sum_{i=1}^{12} \Delta MDE_i \ \ [\mathrm{mm}] \tag{3}$$

-mean depth erosion rate (MDER), corresponding to a period of attack:

$$\mathrm{MDER_i} = \Delta \mathrm{MDE_i} / \Delta t_i \tag{4}$$

The physical significance of the measurements from the ratio (2) is:

ρ - steel density, ($\cong$ 7.85 g/cm^3 for the 16MnCr5 steel [12] and $\cong$ 7.84 g/cm^3 for the 34CrNiMo6 steel [13])

d_p - sample diameter (= 15.9 mm).

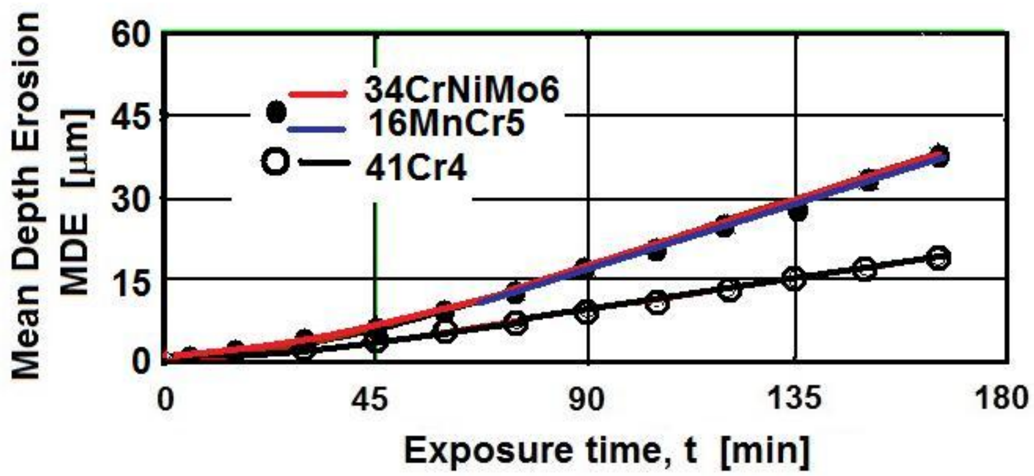

Fig. 3. Mean depth erosion with the duration of cavitation attack

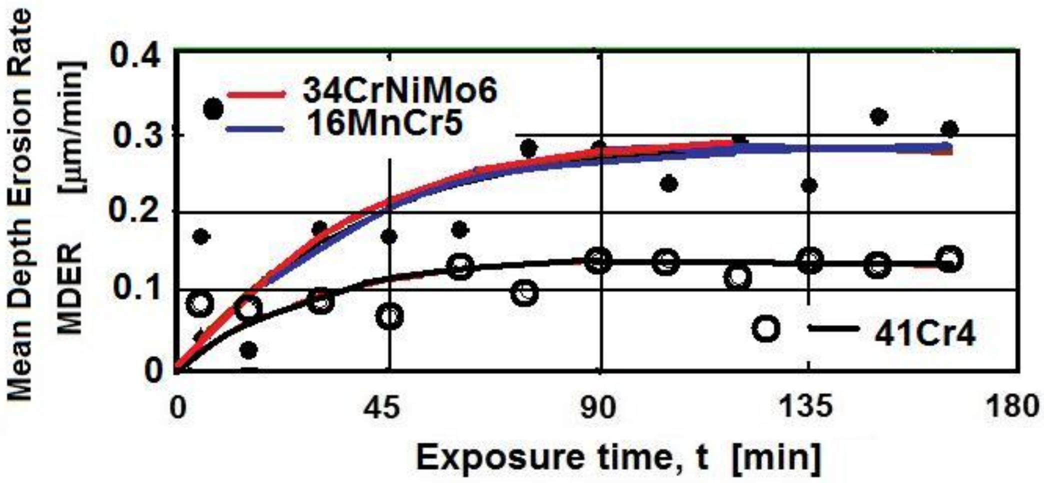

Fig. 4. Mean depth erosion rate with the duration of cavitation attack

In these diagrams, the experimental values are mediated by analytical curves constructed with ratios developed in the laboratory by Bordeasu and a.o. [2], [3], [4].

And the analytical mediation curves show that the two steels have identical behaviors and resistances at the vibratory cavitation intensity. The flattening tendency of the analytical curves at maximum values, according to the results obtained by specialists in the cavitation behavior of the materials, show that the two steels are categorized as those with good resistance to cavitation.
The comparison with the 41Cr4, standard steel in our laboratory, for this type of material, shows that in annealed condition, both investigated steels have lower resistance.

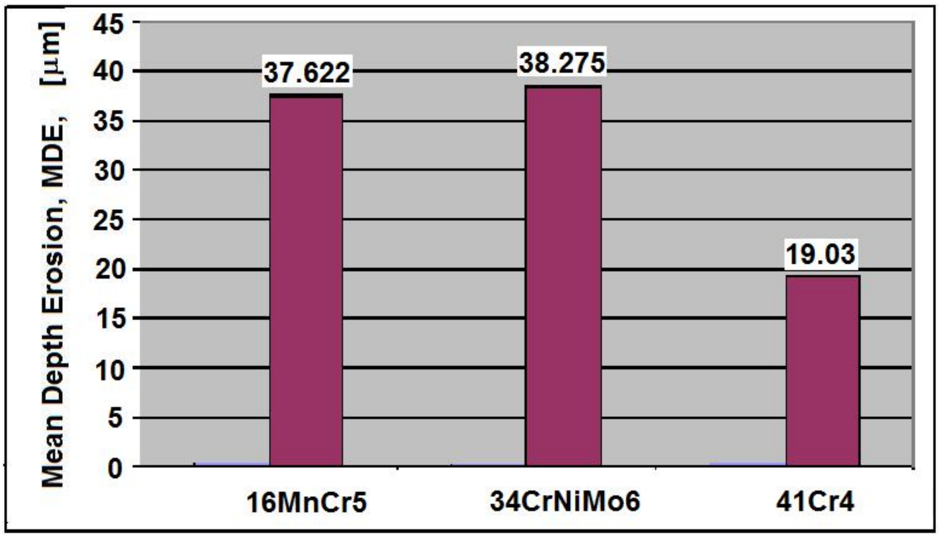

Fig. 5. Comparison of the mean depth of erosion recorded at the end of the test

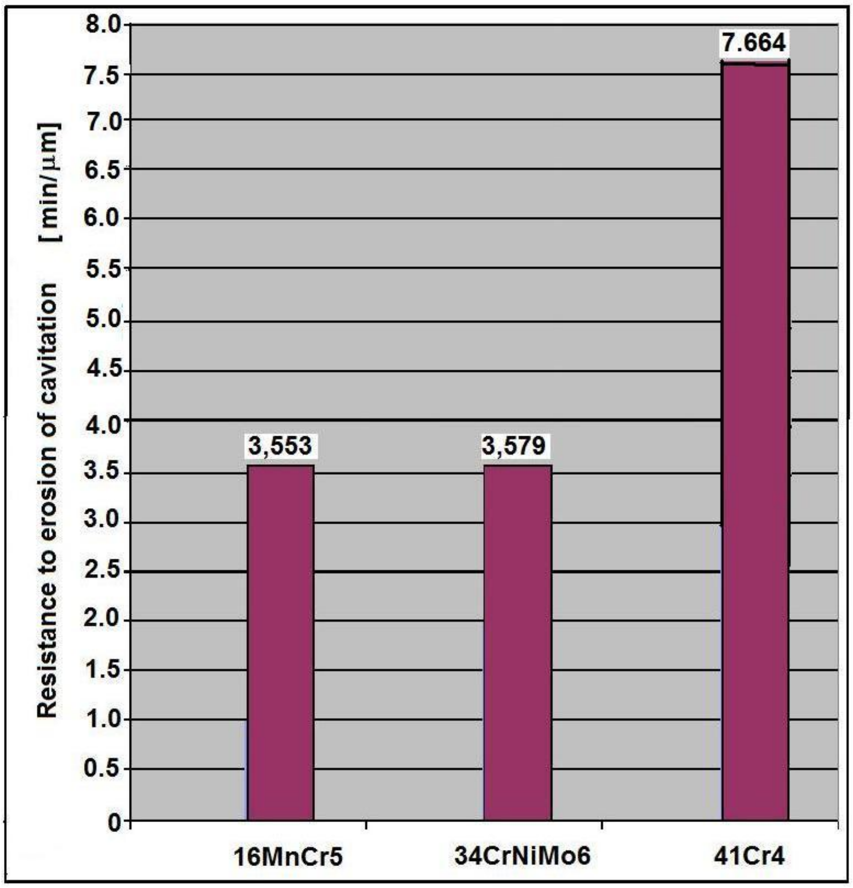

Fig. 6. Comparison of the resistance to erosion of cavitation

The histograms from Figure 5 and 6, built on the final values of the MDE parameter and the stabilizing parameter MDER, allow an approximate evaluation of the resistance of both investigated steels. Thus, compared to the standard steel 41Cr4, the depth of penetration increases by about 97,7% to 16MnCr5 and doubles (about 101%) at the 34CrNiMo6 steel. The about 3% difference between the two steels is in the specific of differences obtained for specimens taken from the same material and the same charge [2].
In terms of resistance to cavitation, expressed by the parameter 1/MDER, Figure 6, there is a decrease by about 115 % for the 16MnCr5 steel and about 114% at the 34CrNiMo6 steel. And the difference between the values of the parameter 1/MDER, of the two investigated steels is insignificant and falls within the specified deviation of samples from the same material and charge.

4. Conclusions

The 16MnCr5 and 34CrNiMo6 steels, in annealed condition, degrade similar to the microjet impact and shock waves generated by the implosion of cavitation bubbles produced by vibrating. The behavior and resistance, to this type of attack, are identical.
From the comparison with the standard steel 41Cr4, results a decrease of resistance at the cavitational attack, but based on the tendency of stabilization at maximum value of the MDER parameter curve, is estimated to be a good one. Also, the comparison with the standard steel, for components of the hydraulic equipment of command, distribution and adjustment, which works in areas with cavitation currents, shows the need of treatment/hardening of the exposed surface, in order to improve it's resistance characteristics to cavitation erosion.

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