
CAVITATION EROSION RESISTANCE FOR A SET OF STAINLESS STEELS HAVING 10 % NICKEL AND VARIABLE CHROMIUM CONCENTRATIONS

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ABSTRACT: *Regardless if the erosion phenomenon takes place in a laboratory facility or in an industrial device cavitation erosion intensity depends on two different factors: the quality of the steel and the intensity of the cavitation. Researches to obtain better materials are done every time in laboratory devices in which the cavitation intensity is very great and the research time is reduced. In most cases, the intensity of cavitation in industrial devices is smaller. The present laboratory researches upon eight stainless steels with great content of austenite are important because such materials are used to repair by welding the affected details. The chemical compositions were established as follows: the Nickel content approximately the same 10%, two contents of carbon 0.1% and 0.036% and eight different Chromium contents between 6 to 24 %. The laboratory facility is a device with piezoelectric crystals respecting the ASTM G32-2010 Standard. The laboratory results show that all the tested steels have very good cavitation erosion resistance; the best obtained result is for the steel having 6% Chromium and 0.1% Carbon with the structure having 32% martensite and 68% austenite. It is interesting to note that this result is better than that obtained for steels with greater content of martensite.*

Key words: *stainless steel, cavitation erosion, microstructure, vibratory test facility*

1. Introduction

The great majority of the modern hydraulic machineries have the runners or the blades made from stainless steels with reduced carbon content (under 0.1%; the reason is to have good weld ability, without heat treatments), low nickel content (about 5%, the reason is the cost reduction) and a high content of Chromium (about 13%). The material structure is composed mostly by martensite giving high mechanical characteristics and also high cavitation erosion resistance. The repair works are done using electrodes with austenitic or austenite-ferrite structure. The problem is to choose electrodes depositing a material with higher cavitation erosion resistance than the genuine one. The cost of the material has not great importance because the used quantity is relatively small. The present research is directed towards such materials with improved cavitation erosion resistance having high content of Chromium and Nickel and austenite structure. If such materials will have also low costs, in the future, it will be possible to use them also for manufacturing the whole runner.

2. Tested materials

The eight materials tested in the present research have a constant nickel content (approximately 10%), and variable chromium and carbon content. From the point of view of carbon content there are divided in two groups: four of them have 0.1% C and the other four 0.036% C. The steels from the first group have the following chromium content 6%, 10%, 18% and 24%. The steels from the second group have the following chromium content 13%, 14%, 16% and 18%.

The cavitation erosion specimens were manufactured from small cast samples subjected to heat treatments. The heat treatment consisted in: homogenization annealing and solution quenching

(with air cooling for steels with martensite and ferrite structures or water cooling for steel with austenite and ferrite structures).

In Table 1 are presented the mechanical characteristics and in Table 2 the micro structural constitutions determined from the Schäßler diagram on the ground of Chromium (Cr_e) and Nickel (Ni_e) equivalents [6]. Because the evaluation of the cavitation erosion resistance is done by comparisons with the steel OH13NDL with martensitic structure [3], [7], (a steel largely used for manufacturing hydraulic equipment in Romania) in both there are given also the characteristics of this stainless steel.

For identification of the tested steels were utilized the principal chemical constituents (nickel, chromium and carbon) and the figures representing the concentration of those three elements. The content was symbolized as follows: for nickel Ni10; for chromium Cr6 to Cr24 (signifying 6 to 24%), for carbon C1 (signifying 0.1% C) or C036 (signifying 0.036%).

Table 1 Mechanical properties [8]

Steel	Carbon content %	R_m [N/mm ²]	$R_{p0,2}$ [N/mm ²]	HB
Ni10Cr6C1	≈ 0.1	1550	1120	489
Ni10Cr10C		1450	1020	447
Ni10Cr18C1		1335	934	372
Ni10Cr24C1		1280	901	307
OH12NDL		650	400	225
Ni10Cr13C036	≈ 0.036	856	618	276
Ni10Cr14C036		341	240	346
Ni10Cr16C036		996	700	309
Ni10Cr18C036		527	369	375

Table 2 Microstructural constitution [8]

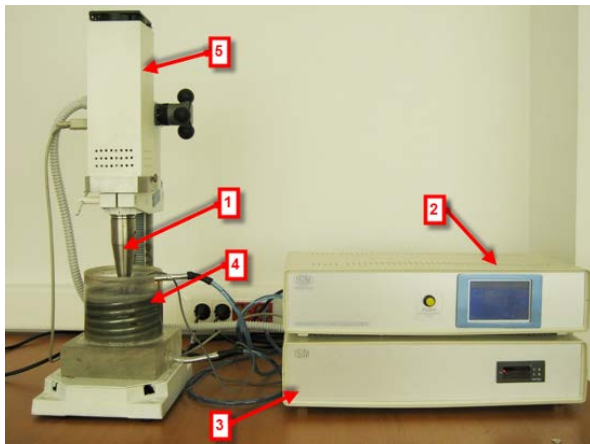
Steel	Cr_e [%]	Ni_e [%]	Structural Constituents
Ni10Cr6C1	11,924	15,173	32% M+68%A
Ni10Cr10C	14,919	14,854	100%A
Ni10Cr18C1	22,414	14,138	98% A+2%F
Ni10Cr24C1	30,362	15,101	81%A+19%F
Ni10Cr13C036	13,209	11,454	55% M+45%A
Ni10Cr14C036	15,022	11,4935	30% M+70%A
Ni10Cr16C036	17,824	11,515	100% A
Ni10Cr18C036	19,610	11,508	93% A+7%F
OH12NDL	13.2	4.45	88%M+12%F

A, austenite, M-martensite, F-ferrite

3. Test facilities and testing method

The specimens were tested in a vibratory device with piezoelectric crystals, realized in the Cavitation Laboratory of Timisoara Polytechnic University [8]. The facility parameters are: the generator power 500 W, the vibration frequency 20 kHz, the double amplitude 50 μ m, the specimen diameter 15.8 mm, all parameters respect the ASTM G32-2010 Standard [2]. As testing

liquid was chosen the drinking water from the urban water-supply network and not the distilled water commonly recommended [3]. The motive was the fact that this water has physico-chemical properties closer to that of the river water where hydraulic machineries runs.



Test facility

1-Horn, 2-Electronic system, 3-Temperature control system, liquid vessel and cooling coil, 5-Ventilation system

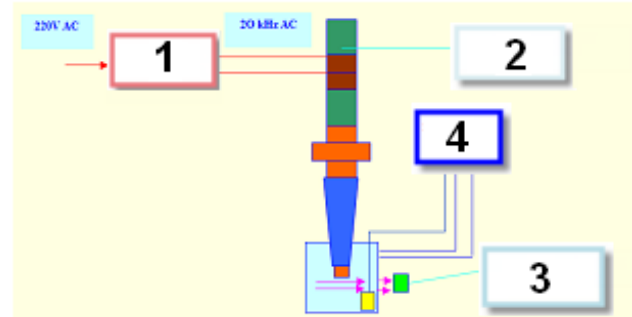


Diagram of test facility

1-Piezoelectric transducer, 2-Ultrasonic generator, 2- Cooling system, 3-Liquid temperature control

Fig. 1. Vibratory device

In conformity with the procedures applied in our laboratory [8] the total cavitation exposure was 165 minutes, divided in 12 intervals (one of 5, one of 10 and the rest of 15 minutes).

To put into evidence the behavior in which the exposed area, respectively the material structure, resisted to cavitation, after the total exposure time (165 minutes) the attacked areas were examined with optical microscopes (magnification x4, x10, x20, x40x and x80) and scanning electron microscopes (magnification x500). For a better examination, the eroded areas were attacked with nitromuratic acid (1/4 HNO₃ – 3/4 HCl and 1-2 glicerine droplets) and a compound formed from 1/10 HNO₃ and 9/10 water. The metallographic analyzes were realized at Bucharest Polytechnic University at the Center for Special Materials Survey (CEMS).

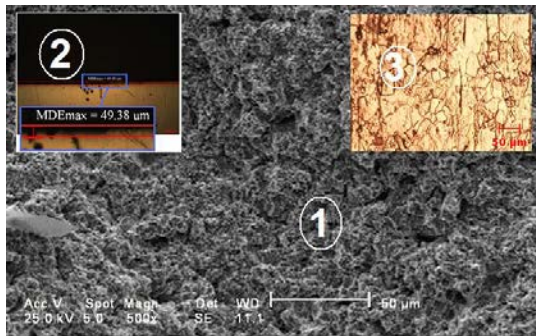
4. Test results. Discussions

In figure 2 are presented images of the eroded areas and their structure after 165 minutes of cavitation exposure obtained with an „OPTICA” microscope and the electronic „Philips XL30 ESEM” microscope.

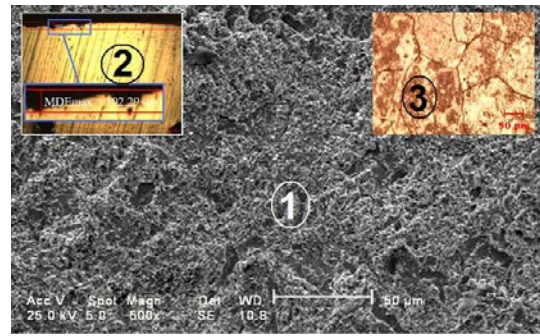
In order to analyze the cavitation structural degradations, fig.2, poz.1, the attacked specimens were axial sectioned, metallographical prepared and studied with a SEM microscope. The following conclusions were obtained:

1. **Ni10Cr6C1** shows a mix aspect with very fine caverns uniformly distributed on the surface, with intergranular propagation of cracks. The fractures have fragile aspect.
2. **Ni10Cr10C1** presents caverns with great dimensions, over 200 μm, inter-granular cracks and cleavage planes. The fractures present a fragile character and are propagated through slipping lines.
3. **Ni10Cr18C1 and Ni10Cr24C1** show caverns with great dimensions, over 200 μm and mix propagation of the fracturing front through inter-granular cracks and cleavage planes. The fracture has a fragile character.
4. **Ni10Cr13C036 and Ni10Cr14C036** present aspects of fragile rupture with fine and very fine caverns. The fracture propagate through inter-granular cracks and cleavage plans.

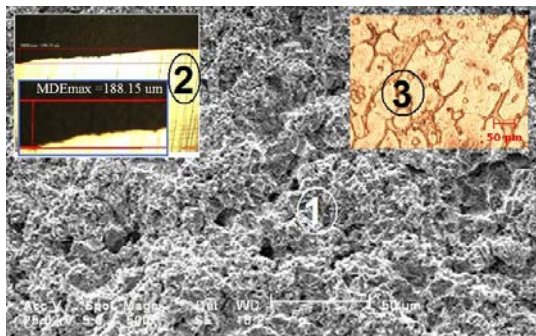
5. **Ni10Cr16C036** has a mix aspect with very fine caverns, uniformly distributed on the surface. There were observed cleavage zones and inter-granular cracks with radial propagation. The fracture has a fragile character with intergranular propagation.
6. **Ni10Cr18C036** shows great caverns. The fracture has a fragile character with intergranular and cleavage propagation. There were observed secondary cracks, cleavage planes and the fracture propagate along slipping lines.



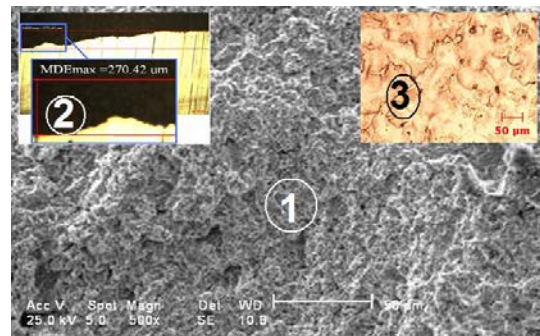
a-Ni10Cr6C1



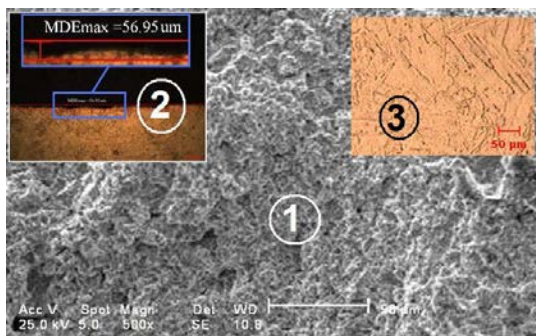
b-Ni10Cr10C



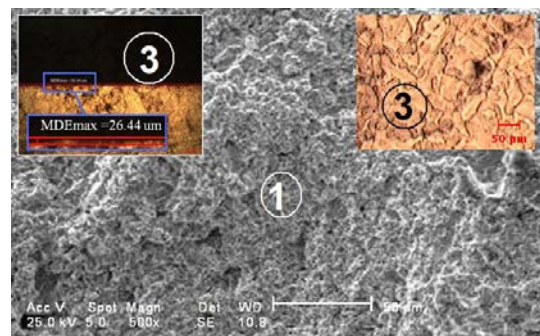
c-Ni10Cr18C1



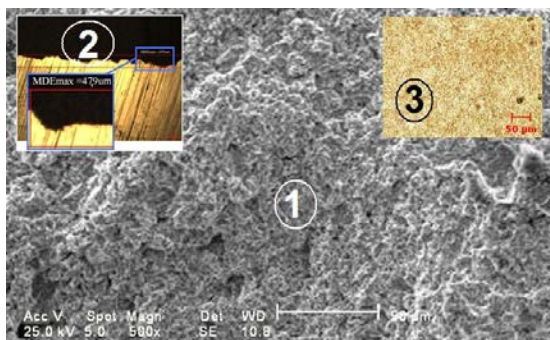
d-Ni10Cr24C1



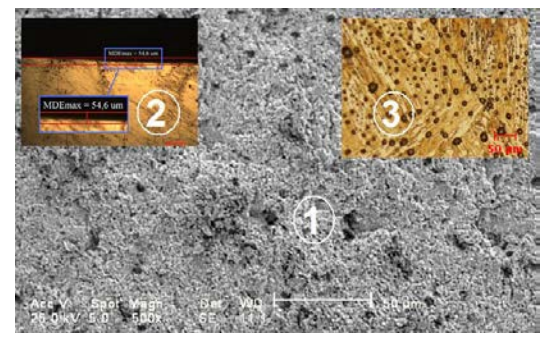
e-Ni10Cr13C036



f-Ni10Cr14C036



g-Ni10Cr16C036



h-Ni10Cr18C036

Fig.2 Images of the structures and the erosions produced on the exposed areas (after 165 minutes of cavitation exposure) (1 – eroded microstructure obtained with a scanning electronic

microscope (SEM), (x500); 2- erosion in a cross section normal to the eroded area with the maximum depth penetration erosion put into evidence, (x4); 3-steel microstructure before the exposure (x500))

The quantitative differences between the cavitation erosion resistance of various steels can be appreciated better by comparing MDER(t) (the mean depth erosion rate curves) of the researched steels with the curve of the standard steel OH12NDL, fig.3, [3,4,7], on the ground of the MDE (mean depth erosions), fig. 4 or the maximum measured depth of the erosion measured in the axial cross-section, fig. 5.

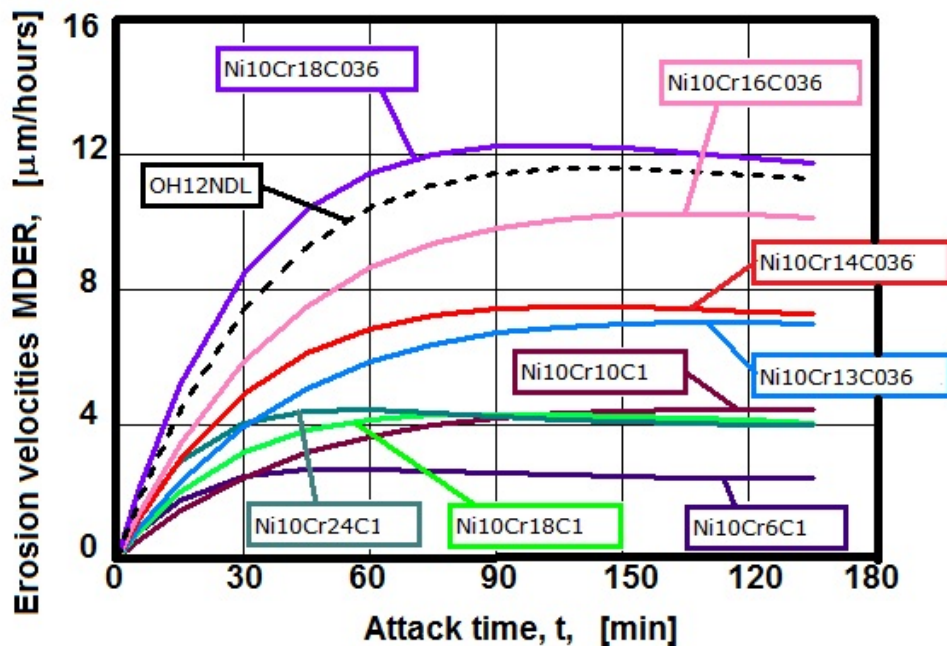


Fig. 3 Mean depth erosion rate against exposure time

The evolution of the curves in fig. 3 present zones of gradually increasing of MDER till 40 to 90 minutes of exposure. For the resistant steels this time is smaller than that for the weaker materials. After reaching the maximum rate this value remains approximately constant. Such an evolution characterises materials with high cavitation erosion resistance [3] [10]. With the exception of Ni10Cr18C036, which is a little weaker, all the tested steels have better cavitation erosion resistance than the standard steel OH12NDL. As a consequence, from the point of view of erosion all the tested steels can be used either for manufacturing or for repair works of details subjected to cavitation.

From the studied materials, Ni10Cr6C1 has the most favorable behavior. The steels Ni10Cr10C1, Ni10Cr18C1, Ni10Cr24C1 even if are a little weaker than Ni10Cr6C1 remain steels with excellent cavitation erosion behavior. The differences between them appear in the first period of exposure and are without importance [1], [3]. The superior behavior of Ni10Cr6C1 which has only 32% martensite in comparison with Ni10Cr13C036 having 55% martensite can be explained by the increased percentage of carbon, which increases the hardness of the material [9].

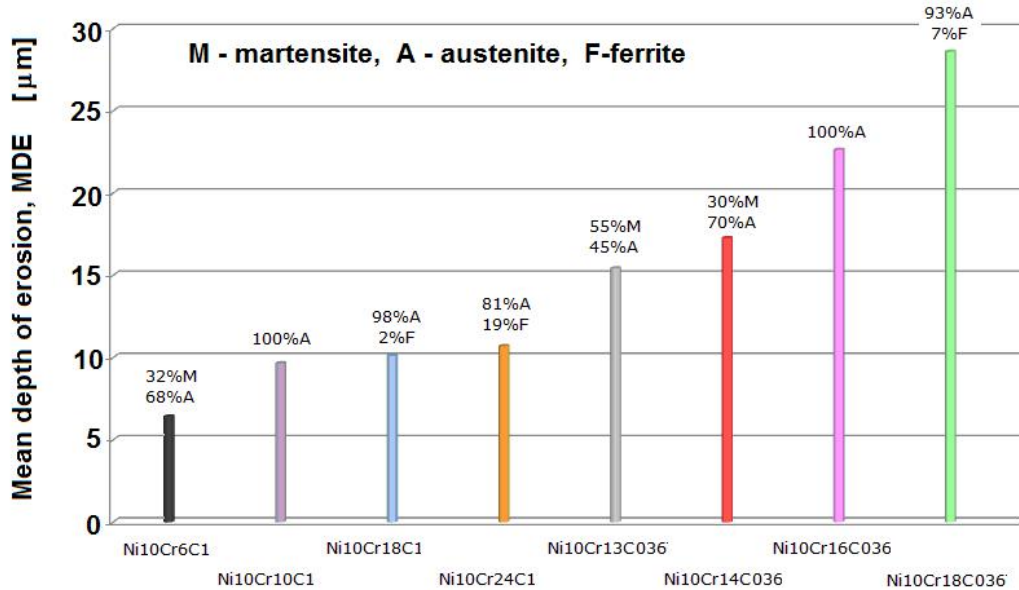


Fig. 4 Cavitation resistance comparisons after the computed mean depth erosion with the microstructure put into evidence

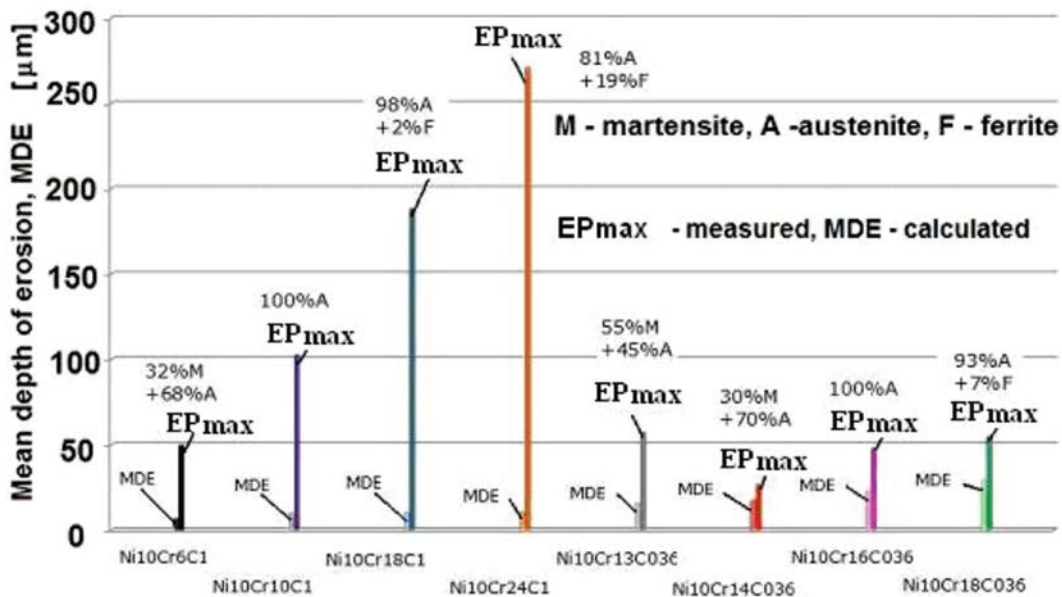


Fig. 5 Comparisons of different penetration depths: „EP_{max} maximum measured erosion penetration”, „MDE computed mean depth erosion” iar in ordonata „Penetration depth PD”

The histogram in fig.4 show that after an exposure of 165 minutes all steels with 0.1% C present mean depth erosions smaller than the steels with 0.036, regardless of the microstructural constitution. We appreciate that this situation is principally determined by the unstable austenite, wich under the bubble implosions impact is locally transformed into martensite. The conclusion results from the comparisons of the excellent resistance steel Ni10Cr16C1 (100% austenitic structure, but unstable) with the lower cavitation erosion resistance steel Ni10Cr16C036 (100% austenitic structure, but stable). This fact shows the beneficial effect of the increased carbon content, even if the structure is the same. Our conclusion is that the carbon content must be reduced but only to a value giving an acceptable weldability but maintaining the unstable austenite. The future researches must be focused on this condition. The increase of the ferrite content for the steels with 0.1 C worsen the resistance to cavitation erosion but this decrease is not in direct proportion with the ferrite increase.

Interesting conclusions appear also for the comparisons between the excellent cavitation erosion steel N10Cr24C1 (81% A and 19% F) and N10Cr18C036 (93% A and 7% F) steel with a wicker cavitation erosion behavior, even if the last has a smaller content of ferrite but has not sufficient carbon.

The histogram in fig.5 show a great difference between the value of the mean depth erosion “MDE” computed from the mass loss of the specimen during the entire exposure (165 minutes) [5], and the greatest depth of caverns “EP_{max}” measured in the axial cross section. We consider that the value chose in ASTM G32 Standard, namely “MDE” is the correct one because it take into account the whole eroded mass. This value and must be compulsory adopted for the evaluation of the various material resistance to cavitation erosion. We also note that the value “EP_{max}” is relatively difficult to appreciate, because it has great variation for different axial cross sections.

5. Conclusions

1. In comparison with the standard material OH12NDL all the researched steels present better cavitation erosion resistance, so they can be used for repairing or even manufacturing blades and runners for hydraulic machines
2. The best cavitation erosion resistance was obtained for the stainless steel having 0.1% C and 6% Cr and a structure with 32% martensite and 68% austenite.
3. From steels having 0.036% C the specimen with 13% Cr having the structure composed by 45% austenite and 55% martensite present the most reduced cavitation erosion resistance.
4. The microstructure has a great influence upon the cavitation erosion resistance. Especially the presence of martensite improves the cavitation resistance.
5. An increased content of carbon content also improves the behavior of the steels to cavitation erosion. All researched steels with 0.036% have smaller cavitation erosion resistance than those with 0.1% C.
6. The Chromium content has an important effect in establishing the proportion between the micro structural constituents and in the same time upon the mechanical properties and the cavitation erosion resistance. The increase of the Chromium content reduces the erosion resistance because the ferrite zone is amplified.
7. The austenite increases the erosion resistance because during the cavitation attack the hardness is increased, or even martensite is formed by bubble implosions.
8. The mean depth of erosion, computed in conformity with the G32-2010 Standard is an excellent indicator for cavitation erosion comparisons between various materials.
10. The maximum penetration depth of the eroded area is not recommended for establishing the cavitation erosion behavior of different materials.

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