Cavitation erosion resistance of two steels with the same percentage of Chromium and Nickel but different Carbon content

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Abstract. Hydraulic machinery repair works necessitate new materials with improved cavitation erosion resistance and simultaneously good welding properties. The present paper is concerned with the behavior at cavitation of two steels with close contents of chromium (approximately 12%) and nickel (approximate 6%) but with different carbon content (for the first 0.1% C and the second 0.036% C). The reduced carbon content is necessary for an easy welding repair work. As a result of the different chemical content, as is shown by the Schäffler diagram, the steel containing 0.1% C has a structure formed by 60% austenite and 40% martensite while those with 0.036% C has completely martensitic structure. The laboratory tests were done in two vibratory devices one with piezoelectric crystals, respecting the ASME G32-2010 Standard and the other a magnetostrictive vibratory device with nickel tube. The evaluation of the cavitation resistance was obtained with the help of cavitation erosion characteristic curves MDE (t) and MDER (t). For analyzing the steel degradation, the eroded areas were also subjected to microscopic investigations. The results show that the steel with 0.1% C has better cavitation erosion behavior than that of the steel with 0.036% C.

1. Introduction

Two great problems must be solved by the researchers, the manufacturers and the maintenance personnel, namely the time increase of the good running of the machinery and the reduction of the repair working time. This implies the use of steels with excellent cavitation erosion qualities but in the same time with the capacity to accept easy welding of the eroded zones. From the cavitation erosion resistance, the researches and the field experience show that the stainless steels with martensitic structure are suited for this purpose both from the point of view of resistance and costs [1], [3]. The welding repair work is not a very easy one but is possible especially by using electrodes with austenite or austenite ferrite structure, the electrodes cost is high but the quantities employed is not very great. Another problem is the carbon content of the base material. In most cases this content is chosen under 0.1% in order to reduce the welding difficulties and to avoid post welding cracks. This was the base to subject to laboratory tests two steels with different carbon contents (0.112% and 0.36%) but the same
chromium (12%) and nickel (6%) contents. Test results obtained with two vibratory devices, one having a nickel magnetostrictive tube (noted T1) and the other with piezoelectric crystals respecting the recent ASTM G-32 2010 Standards put into evidence the influence of carbon content. It resulted that the carbon content must not be extremely reduced because it severely diminishes the cavitation erosion qualities of the steel.

2. Tested materials and testing facility. Discussion
The tested specimens were manufactured from cast bars after a mixing formula conceived by the experts from the Bucharest Polytechnic University, Center of Special Materials Survey. In the following, for these stainless steels were use the notations:
1 - Cr12Ni6C1- for steels with 12.06% chromium, 5.95% nickel, 0.112% carbon, 1.67% manganese, 0.023% cobalt, 1.69% silicon, 0.031% molybdenum, 0.01% tantalum, 0.031% niobium, 0.047% titan, 0.047% vanadium, 0.016% wolfram, 0.92% aluminum, about 76.94% iron, the rest being small quantities of accompanying chemical elements.
2 - Cr12Ni6C036 - for steels with 12.059% chromium, 5.597% nickel, 0.036% carbon, 0.28% manganese, 0.002% cobalt, 0.461% silicon, 0.039% molybdenum, 0.009% niobium, 0.073% vanadium, 0.009% wolfram, 0.064% aluminum, about 81.37% iron, the rest being small quantities of accompanying chemical elements.

The manufacturing processes of the specimens inclusive the heat treatments were identical for both materials, the chemical composition and the resulted structure give differences between the mechanical properties, which are not analyzed in the present paper. The testing liquid was water taken from the urban grid at 22±1°C. The resistance to cavitation erosion was obtained in two vibratory devices with different parameters. The T1 device is of the magnetostrictive type with nickel tube (vibration amplitude 94 μm, frequency 7000 Hz, specimen diameter 14 mm, power of the ultrasonic generator 500 W). The T2 device was recently realized, respecting the ASTM G32-2010 Standard, has piezoelectric crystals (vibration amplitude 50 μm, frequency 20 kHz, specimen diameter 15.8 mm, power of the ultrasonic generator 500 W) [5], [9]. Both test facilities were realized in the Cavitation Laboratory of Timisoara Polytechnic University.

The testing procedure (cleaning, washing, drying, weighing and specimen maintenance) and the duration to cavitation exposure (total exposure 2.75 hours with two intermediary periods of 0.83, 0.167 and the rest of 0.25 hours) were those used in the last 40 years in our laboratory.

The experimental results are presented by the characteristic curves (Fig. 1 and 2) which gives the time evolutions of both cumulative mean depth erosions (MDE) and mean depth erosion rates (MDER) for the tested materials. Supplementary are given histograms which present comparisons between the mean depth cavitation resistance 1/MDER of the tested steels (Fig.3) as well as comparisons between mean depth erosions (MDE) and maximum depth erosions MxDE). This comparisons are presented for both testing facilities (Fig. 4). The MxDE were microscopically measured in axial cross sections carefully selected.

The parameters MDE and MDER were computed from the mass loss recorded after each testing period by using the following relations:

\[
MDE = \sum_{i=1}^{12} \left( \frac{4 \cdot \Delta M_i}{\rho \cdot \pi \cdot d_p^2} \right) \text{[mm]} \\
MDER = \frac{4 \cdot \Delta M_i \cdot 60}{\rho \cdot \pi \cdot d_p^2 \cdot \Delta t_i} \text{[mm/hours]}
\]

where:
\(\Delta M_i\) - is the mass loss of the period “i”, measured in grams,
\(\rho\) – is the steel density in grams/mm³,
\(\Delta t_i\) – is the the duration of the period “i”,

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i = 1, 2, 3...12 – is the cavitation period (for i = 1, $\Delta t = 0.083$ hours, for i = 2, $\Delta t = 0.167$ h, and for i= 3...12, $\Delta t = 0.250$ h is equal for each period),

d_p – is the specimen diameter in mm.

The evolutions of the curves MDE(t) and MDER (t) show the behavior of the used steels at mechanical stresses and local fatigue, generated by the impact with the forces developed through the bubble implosions.

In order to establish the performances of the two tested steels in Fig. 1 and 2 is given also the behavior of the steel OH12NDL, with martensitic structure, used in the past for manufacturing numerous hydraulic turbines in our country [1], [2].

The parameter $1/\text{MDER}$ chosen to characterize the steels resistance at cavitation erosion is in most cases the inverse of the stabilization MDER value and in some rare cases the MDER value for the maximum exposure time.
From the diagrams it result the following conclusions:

- Regardless of used facility for generating vibratory cavitation (T1 or T2) the time evolution of the curves MDE(t) Fig. 1, and MDER(t) Fig. 2 is similar. The differences between the erosion mean depth erosion values is given by the difference of the parameters devices. The erosion intensity of T1 is greater than those of T2 and that gives for T1 greater cavern depth, especially the maximum depth is impressive. On the other hand, the eroded the area resulted with T2 covers approximate 85% of the whole area subjected to cavitation while for T1 only 60% of the area is affected.

- The mean depth erosion rates have the tendency to become stable for the maximum attained value. This behavior, in conformity with the former researches undertaken in Cavitation Laboratory of Timisoara Polytechnic University [1], [2], [5], is specific for steels with high cavitation erosion resistance, or for those with hardened superficial layer.

- By comparing the cavitation erosion resistances Fig. 3 or the maximum values for the mean depth erosions, Fig.2 it has been ascertained that the smallest cavitation erosion resistance is that of the steel
Cr12Ni16C036. The explanation is the low content of carbon which reduces the hardness of the area exposed to cavitation [5].

- By comparing the cavitation erosion behavior of the tested steel with that of OH12NDL steel resulted that both have better resistance and can be recommended for manufacturing of hydraulic turbines runners and blades.

- Although, in literature [1], [3], [4] the martensite steels are considered to have the highest cavitation erosion behavior, the data presented in Fig. 3 and 4 show that some steels with mix structure such as Cr12Ni6C1 with 60% austenite and 40% martensite exhibit superior qualities from this point of view and can replace the Cr12Ni6C036 steels used long time for manufacturing pump impellers or turbine runners [1], [2]. Because austenite has excellent welding capabilities, in the future researches, steels with different structure as the martensitic one must be analyzed, taking into account also the manufacturing qualities, mechanical characteristics, and the prime cost. The carbon content must be under 0.1% but not very low, because it gives also good cavitation erosion qualities.

- The comparisons between the mean depth erosion (MDE) and the maximum depth erosion (MxDE) must be maintained in use. The value of MDE is the important number for comparisons, but for two steels with the same MDE but different MxDE the better is those with low values of maximum depth of erosion.

To have an image upon the effect of the test facilities parameters upon the resulted cavitation erosion in Table 1 there are presented the ratios between the mean depth erosions rates (in stable zone) for the researched steels.

| Steel        | Cr12Ni6C1 | Cr12Ni6C036 |
|--------------|-----------|-------------|
| MDERS T1     | 8.071     | 6,163       |
| MDERS T2     |           |             |

From table 1 it can be seen that the cavitations erosion intensity is greater for the device with nickel tube. Examining with a scanning electronic microscope the eroded areas of the Cr12Ni6C1 steel specimens both for T1 and T2 (see Fig.1) there were observed uniform erosions and zones with fragile rupture aspect. This is the result of the fact that both martensite and austenite with small quantities of chromium carbides in the structure assure a great cavitation erosion resistance. Also, the eroded area has a mix aspect with fine caverns (1…5 μm), cleavages surfaces and inter granular cracks. The same examinations made for the specimens from Cr12Ni6C036, regardless if they are eroded with the facility T1 or T2 (see Fig. 1) show erosions with irregular destructions and big caverns.

3. Conclusions
1. Laboratory results show that both tested steels present very good cavitation erosion resistance and can be used for manufacturing pieces heavy exposed to such strains as for example hydraulic machinery runners and blades.
2. The tests effected on two different facilities T1 and T2 show that Cr12Ni6C1 steel with an initial 60% austenite and 40% martensite structure has better cavitation erosion resistance than Cr12Ni6C1 steel with an initial 100% martensite structure.
3. In the study were not considered the changes that occur in the steels structure due to mechanical impact of the attack surface with shock waves or micro jets generated by the implosions of cavitation bubbles.
4. Regardless of the different running parameters, both test facilities, give approximate the same result when the used stainless steels are compared.
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