Researches upon cavitation erosion behavior of some duplex steels

I Bordeasu¹, M O Popoviciu², I Mitelea¹, L M Micu¹, C Bordeasu¹, C Ghera¹ and A Iosif³

¹Politehnica University of Timisoara, Faculty of Mechanical Engineering, Mihai Viteazul Street, Nr. 1, 300222 Timisoara, Romania
²Academy of Romanian Scientists, Mihai Viteazul Street, Nr. 1, 300222 Timisoara, Romania
³Politehnica University of Timisoara, Faculty of Civil Engineering, Traian Lalescu Street, Nr. 2, 300223 Timisoara, Romania

E-mail: ilarica59@gmail.com

Abstract. This paper presents the cavitation erosion behavior of two stainless steels having a duplex structure formed by austenite and ferrite. The conclusions were obtained by using both the cavitation erosion characteristic curves and the pictures of the eroded surfaces obtained with performing optic microscopes. The researches were focused upon the optimal correlation between the cavitation erosion resistance and the rate of the two structural constituents. The tests were done with T2 facility, with ceramic crystals, which integrally respects the ASTM G32-2010 Standard. The obtained results present the cumulative effect upon cavitation erosion of the chemical composition, mechanical properties and the structural constituents. The results of the researches are of importance for the specialists which establishes the composition of the stainless steels used for manufacturing hydraulic machineries or other devices subjected to cavitation erosion.

1. Introduction

Duplex stainless steel is a family of materials with austenite-ferrite structure, in which the chemical composition, severally controlled, contains between 21-25% Cr and 5-7% Ni. In smaller quantities they may contain also molybdenum and nitrogen. The common heat treatment is quenching in water.

Those steels are used in fields where: corrosion resistance is important, inclusively by pitting, the welding is easy to be performed and the mechanical characteristics are maintained approximately unchanged at temperatures between (-50-+280) °C [1]. Taking into account the enounced characteristics we put the question of employing those stainless steels also for manufacturing and repair works of the hydraulic machineries elements subjected to cavitation erosion.

2. Researched materials

The researched steels X2CrNiN23-4 and X2CrNiMoN22-5-3, in conformity with 100088-1, 2, 3-2005 Standard [2], have the following chemical compositions and mechanical properties:

- steel X2CrNiN23-4: <0.03%C, (21.5-24.5)%Cr, (3.0-5.0) %Ni, (0.05-0.6)%Mo, (0.05-0.2)%N, <1.0% Si, <2.5%Mn, (0.05-0.06)%Cu, <0.04%P, <0.03%S, rest iron; ultimate strength Rm = 670 MPa, yield limit Rp0.2 = 450 MPa, Brinell hardness = 210 daN/mm².
- steel $X_2CrNiMoN22-5-3$: $<0.03\%$C, $(22-23)\%$Cr, $(4.5-6.5)\%$Ni, $(3-3.5)\%$Mo, $(0.14-0.20)\%$N, $<1.0\%$ Si, $<2.0\%$ Mn, $<0.03\%$P, $<0.02\%$S, rest iron, ultimate strength $R_m = 750$ MPa, yield limit $R_{p0.2} = 510$ MPa, Brinell hardness $= 230$ daN/mm$^2$.

For the employed samples, the actual chemical compositions and mechanical properties were determined in the Timisoara “Politehnica” Laboratories. These values are:
- steel $X2CrNiN23-4$: $0.02\%$C, 21.17\%Cr, 4.27\%Ni, 0.49\%Mo, 0.06\%N, 0.95\% Si, 2.43\%Mn, 0.057\%Cu, 0.035\%P, 0.013\%S, rest iron, ultimate strength $R_m = 667$ MPa, yield limit $R_{p0.2} = 454$MPa, Brinell hardness $=203$ daN/mm$^2$
- steel $X2CrNiMoN22-5-3$: 0.02\%C, 22.72\%Cr, 5.23\%Ni, 0.19\%N, 0.22\% Si, 0.47\%Mn, 0.03\%P, 0.013\%S, rest iron, ultimate strength $R_m =743$ MPa, yield limit $R_{p0.2} =504$ MPa, Brinell hardness $=217$ daN/mm$^2$

The pitting corrosion index PRE, computed with the relation (1) [1]:

$$PRE = %Cr + 3.3\times%Mo + 16\times%N$$ \hspace{1cm} (1)

is 23,747 for the steel $X2CrNiN23-4$ and 36,122 for the steel $X2CrNiMoN22-5-3$, both presenting a high resistance to pitting corrosion.

Using the Schäffler diagram (Figure 1) and the equivalent values for chromium (CrE) and Nickel (NiE), determined with the specific relations [3], [4], the approximate structure of the researched steels is: 18 \% austenite and 82 \% ferrite for $X2CrNiN23-4$ (CrE $\approx 23.85 \%$, NiE $\approx 6.085 \%$) and 10 \% austenite and 90 \% ferrite for $X2CrNiMoN22-5-3$ (CrE $\approx 26.19 \%$, NiE $\approx 6.065 \%$). The microscopic aspects of the basic structure of those steels are presented in Figure 2.

![Schäffler Diagram](image)

**Figure 1.** Positions of the researched steels in the Schäffler diagram
A-stainless steel $X2CrNiN23-4$; B-stainless steel $X2CrNiMoN22-5-3$; C- comparison stainless steel OH12NDL

As can be seen in the Schäffler diagram, the chemical components of the studied steels conducted to important structural differences. The steel $X2CrNiN23-4$ (symbolized with A) being in the zone with austenite and martensite. On the contrary the steel $X2CrNiMoN22-5-3$ (symbolized with B) is in the zone with austenite and ferrite. In the same diagram with the symbol C is marked the martensitic stainless steel OH12NDL, used on a large scale in the former Soviet Union but also in Romania for manufacturing hydraulic turbines runners. This steel presented a good behavior to cavitation erosion.
3. Researched procedure. Experimental results

The cavitation erosion behavior was realized in the Timisoara Polytechnic University Cavitation Laboratory in the test facility T2 with piezoelectric crystals [5], [6], [7], [8]. The device was realized in conformity with the ASTM G32-2010 Standard [9]. The device is provided with a lot of instrument to maintain the running parameters at constant values. Both test maximum test exposure, the intermediary measuring intervals, the weighing procedure the number of tested specimens, were chosen in conformity with the procedure adopted in our [5], [6], [10]. Because the results may be applied for the use of the steels for manufacturing or repair works, especially by welding, of hydraulic machineries details the liquid used for tests was drinking water from urban water supply system at a temperature of $22 \pm 1^\circ C$.

The previous researches [11] put into evidence that for 165 minutes total exposure time, accepted by our laboratory as sufficient for attaining a constant erosion rate, the corrosive effect of the drinking water is negligible and deionization of water is not necessary. Some tests recorded previously show that the results are not influenced by the quality of water, especially for corrosion resistant materials such as the steels X2CrNiN23-4 and X2CrNiMoN22-5-3.
With the purpose to appreciate the time evolution of cavitation erosion behavior in Figures 3 and 4 is presented the evolution in time of the mean depth erosion (MDE) and the mean depth erosion rate (MDER).

Figure 3. Evolution of mean depth erosion with time
1- Stainless Steel X2CrNiMoN22-5-3; 2 - Stainless Steel X2CrNiN23-4; 3 - Comparison Steel OH12NDL

Figure 4. Evolution of MDER with exposure time
1- Stainless Steel X2CrNiMoN22-5-3; 2 - Stainless Steel X2CrNiN23-4; 3 - Etalon Stainless Steel OH12NDL

The curves of the time evolution in Figures 3 and 4 were obtained analytically, using the Bordeasu method [12]. The mean points (mean of three measurements) are also presented in Figures 3 and 4. The shape of the curves is specific for materials with good cavitation erosion behaviors [3], [4], [13].

It can be seen in Figures 3 and 4 that in comparison with the reference standard OH12NDL, both researched steels have smaller resistance. From Figure 1 result that after 165 minutes of exposure the mean depth erosion for the steel X2CrNiMoN22-5-3 is with 15.74 % greater and for the steel X2CrNiN23-4 is with 5.88 % greater than that of the standard steel.
Taking into consideration the parameter 1/MDER\textsubscript{165} (MDER\textsubscript{165} being the level value of the curve MDER(t), where the curve have the tendency to remain horizontal), it results that: the steel X2CrNiN23-4 in comparison with the standard steel OH12NDL has a cavitation resistance diminished with approximate 25% and the steel X2CrNiMoN22-5-3 a cavitation resistance diminished with approximate 10%. The principal motive of those reduced cavitation erosion resistance is the microstructure constitution, where ferrite is the wickets component but also the stable austenite is eroded in a greater measure than martensite. The standard steel has approximate 74% martensite and only 26% ferrite \cite{3}, \cite{6}, in comparison with the researched steels (82% for the steel X2CrNiN23-4 and 90% for X2CrNiMoN22-5-3).

As can be seen in Figures 3 and 4 from the researched stainless steels the better behavior present the steel X2CrNiN23-4 (symbolized by A in Schäffler diagram) has a cavitation resistance approximate with 17% greater than the steel X2CrNiMoN22-5-3. The explanation is the greatest proportion of austenite (18%) and the posible transformation of the austenite in martensite, as a consequence of here position at the boundary between austenite and martensite. This structure gives increase of the cavitation resistance of X2CrNiMoN22-5-3, even if the mechanical characteristics are worse than those for X2CrNiN23-4. This conclusion is sustained also by the good behavior of the steel OH12NDL which has worse mechanical characteristics with exception of the Brinell Hardness (ultimate strength R\textsubscript{m}=650MPa, yield limit R\textsubscript{\textgamma}=400 MPa, Brinell Hardness HB=225 daN/mm\textsuperscript{2}, \cite{3}, \cite{6}). As a consequence, for close values of mechanical characteristics the microstructure is extremely important for cavitation erosion resistance.

In Figures 5-8 there are presented images of the roughness before and after the total cavitation exposure. Figures 5 and 7 present the roughness obtained before cavitation, with a MITUTOYO device at the Timisoara National Institute for Research-Development in Welding and Material Tests. The images of Figures 6 and 8 show the aggressively cavitation erosion expressed in the level of the roughness Ra, Rz si Rt, Figures 6a si 8a, measured after three directions Figures 6c and 8c.

![Figure 5. Surface roughness before cavitation exposure X2CrNiN23-4](image_url)
Figure 6. Roughness and microstructure for X2CrNiN23-4 after cavitation exposure

Figure 7. Surface roughness before cavitation exposure X2CrNiN23-4
As can be seen from comparisons of the roughness parameters (Figures 6a and 8a), but also from the microstructure photos (Figures 6b and 8b), the level of deterioration of the steel X2CrNiMoN22-5-3 is greater than that of the steel X2CrNiN23-4. These observations correspond to those seen in the evolutions of the MDE and MDER. The better behavior of the steel X2CrNiN23-4 is given by the transformation of austenite in martensite under the influence of the stresses determinate by the cavitation bubbles implosions.

4. Conclusions

a. With different chemical compositions and the structure formed from austenite and ferrite, the stainless steels X2CrNiMoN22-5-3 and X2CrNiN23-4 present visible differences of the cavitation erosion behavior. The difference is given by a greater proportion of austenite. The steel X2CrNiN23-4 has a greater proportion of austenite (approximate 18 %) and has also a greater cavitation erosion resistance in comparison with the steel X2CrNiMoN22-5-3 (approximate 10 % austenite).

b. Even if the cavitation erosion resistance is smaller than that of the standard steel OH12NDL, the cavitation erosion resistance is acceptable and those steels can be used for repair works, through welding, of the eroded zone of the runners or runner of hydraulic machineries.

c. In the case of duplex steels (with the structure formed from austenite and ferrite) a good structure proportion confers a greater cavitation erosion resistance regardless of the principal mechanical (Rm, Rp0.2 si HB).
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