Influence of volumic heat treatments upon cavitation erosion resistance of duplex X2CrNiMoN 22-5-3 stainless steels

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Abstract. The stainless steels Duplex 2205 with austenite and ferrite structure have mechanical characteristics close to those of martensite stainless steels but a better corrosion resistance; these steels are very sensitive on the heat treatments. Present work studies the cavitation erosion for those steels for three different heat treatments: simply quenched, annealed at 475°C post quenching and annealed at 875°C. The researches were undertaken at Timisoara "Politehnica" University in the Laboratory of Material Science and the Laboratory of Cavitation, using the T2 facility which integrally respects the recommendation of ASTM G32-10 Standard. The best results were obtained with the specimens annealed at 875°C. In comparison with the stainless steel 41Cr4, with very good cavitation erosion qualities, all tested steels presented also good erosion resistance. So, Duplex 2205 steels can be used for details subjected to cavitation. The best results are obtained by increasing both the hardness and the quantity of the structure constituent with better cavitation erosion resistance, in our case the alloyed austenite.

1. Introduction

For manufacturing marine structures carrying chemical aggressive substances frequently are used the stainless steels Duplex 2205/ X2CrNiMoN 22-5-3 because it has very good mechanical properties (ultimate resistance 736 N/mm^2, elongation 34%, yield point 570 N/mm^2) but also because it has excellent welding qualities. The welded joints have both good tenacity and corrosion resistance [1], [5], [6], [7], [13], [15], [18]. Important is also the fact that after the detail wear out, the material can be melted and reused. This steel is very sensitive to heat treatments and the effect of these treatments must be thoroughly known [9]. By quenching the Duplex 2205 with heating at a temperature of (1049…1149) °C the structure obtain a small quantity of ferrite, regardless of the cooling velocity and by tempering at temperatures between (449…599)°C a good structural hardening is obtained [9]. For the same content in Cr and Ni, the behavior of the Duplex stainless steel to pit corrosion is superior to those of austenitic steels [5]. In present, there are undertaken numerous studies for increasing also the mechanical properties of Duplex steels, through volume heat treatments. Taking into consideration these tendencies the present paper reveals the importance of adequate heat treatments in order to obtain an increased resistance to cavitation erosion of the X2CrNiMoN22-5-3 Duplex stainless steel.

The cavitation researches were performed in Timisoara Cavitation Laboratory using a vibratory facility, strictly respecting the recommendation of ASTM G32-10 Standard. To ascertain the level of cavitation erosion resistance, the obtained values were compared with those of the stainless steel 41Cr4, a material with good cavitation behavior both in laboratory and processing plants.

2. Researched material and applied treatments

The researched material is Duplex 2205 stainless steel, symbolized X2CrNiMoN22-5-3 in conformity with the European Standard EN 10088 [12]. For comparisons, was chosen the stainless steel 41Cr4, considered with good cavitation erosion behavior [1]. The chemical composition is presented in table 1 and the mechanical characteristics in table 2.

Table 1. Chemical composition (%) of the researched steels [1], [9], [13]

Steel	C	Mn	P	S	Si	Ni	Cr	Mo	N
X2CrNiMoN22-5-3	0.017	1.837	0.024	0.0002	0.313	5.019	22.083	2.585	0.1502
41Cr4	0.445	0.561	-	0.09	0.28	-	0.94	-	-

Table 2. Mechanical characteristics before heat treatment [1], [14]

Steel	Hardness HB	Yield point $Rp_{0,2}$ (N/mm^2)	Ultimate strength R_m (N/mm^2)	Elongation at fracture A_5 (%)
X2CrNiMoN22-5-3	240	450	Min.650	25
41Cr4	238	790	808	12

From Table 1 it can be seen that in comparison with 41Cr4, the stainless steel X2CrNiMoN22-5-3 has a smaller content of carbon and consequently a better welding ability. In the same time 41Cr4 has better mechanical characteristics ($Rp_{0,2}$ and Rm) which improve the cavitation erosion resistance [1], [2], [17], [18]. The heat treatments were done in the Laboratory for Material Science and the cavitation erosion tests in the Cavitation Erosion Laboratory, both belonging to Timisoara "Politehnica" University. The cavitation erosion tests respect the Standard ASTM G32-2010 [10], [11].

The tested material X2CrNiMoN22-5-3 was subjected to three different heat treatments:

A. quenching for putting into solution by heating at 1060°C during 30 minutes and after that cooled in water;
B. quenching in the same way but subjected to annealing by heating at 475°C during 4 hours, followed by air cooling;
C. quenching in the same way but with annealing by heating at 850°C during 2 hours, followed by air cooling.

After the heat treatments the samples hardness was measured. The mean results are:

- 275 HV1 for sample A
- 330 HV1 for sample B
- 362 HV1 for sample C

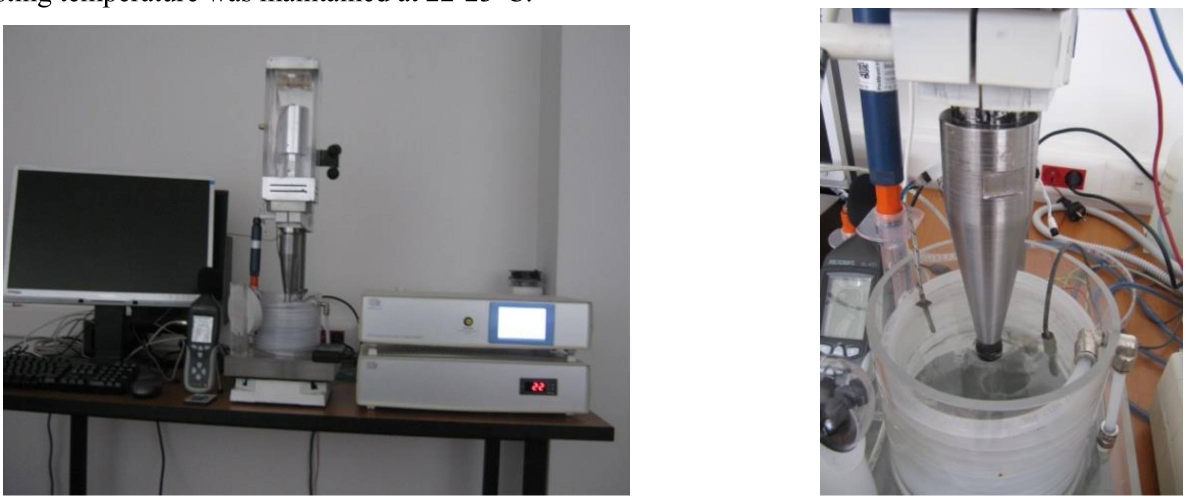
For each type of heat treatment were subjected to cavitation erosion three specimens, following the recommendations of the Standard ASTM G32-2010 [4], [10]. The mean value of these three results was considered representative for cavitation erosion. Figure 1 present the surface aspect of the heat treated specimens before the cavitation tests.

Specimen A Specimen B Specimen C

Figure 1. Surface aspect before cavitation erosion exposure (minute 0)

3. Experimental results

From each sample were extracted five specimens, three of them were tested respecting the ASTM G32 Standard. The total duration of the cavitation test was 165 minutes divided in 12 periods (the first two were shorter 5 and 10 minutes the remaining ten were of 15 minutes). The test facility of the Timisoara Polytechnic University Cavitation Laboratory is presented in Figure 2 and respect integrally the ASTM Standard. All the parameters of the testing facility were permanently controlled and maintained at same level [2], [3]. As testing liquid was used drinking water from the urban net. The testing temperature was maintained at 22-23°C.



a) b)

Figure 2 Test devices T2 with piezoelectric crystals
a) – general view, b) – details: beaker, specimen and horn

After each of the 12 testing periods the specimens were carefully washed, dried and weighted. The mean value of these three tested specimens was considered the mean depth of erosion and was used for plotting the characteristic curves MDE(t) (mean depth erosion against time). A similar procedure was used for MDER(t) (mean depth erosion rate against time) [16], [17], [8]. One specimen from each group was longitudinally cut-off (see Figure 3) in order to analyze the shape of the eroded area, the maximum depth of the erosion and possible cracks propagation in the structure (Figure 6). For structural microscopic analyze the cut specimens were embedded in resin (Figure 3). To evaluate the cavitation erosion resistance were used the mean depth erosion MDE, Figure 4, and mean depth erosion rate MDER, Figure 5, as recommended by ASTM G32-10 [16]. In Figure 4 are given photographic images after three exposure times (60, 120 and 165 minutes). Those images, in correlation with figure 6 show clearly the effect of the volume heat treatment upon the behavior at cavitation erosion.

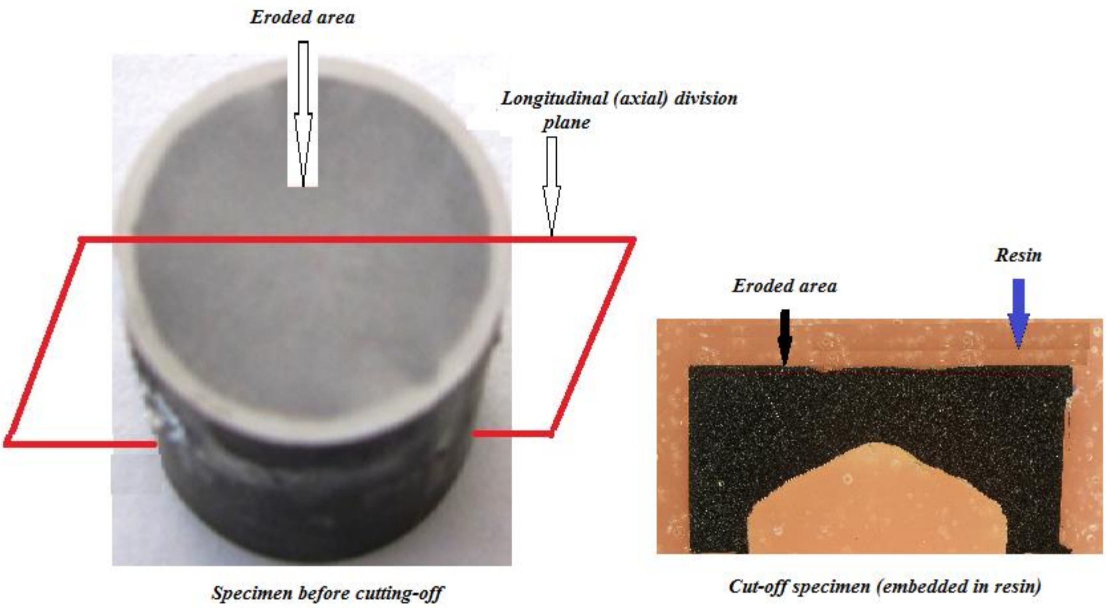
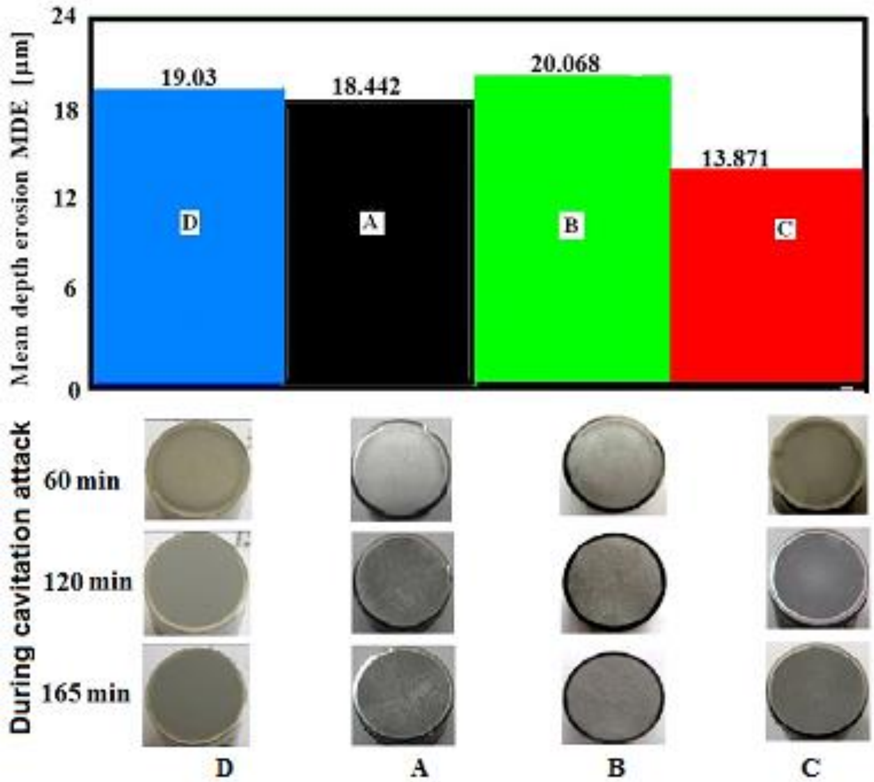


Figure 3. Specimen preparation for microscopic analyse.



-Eroded areas for three different exposures-

Figure 4. Mean depth erosion obtained after 165 minutes of cavitation exposure. There were used the following symbols:
A) Duplex 2205 Quenched and cooled in water, **B**) Duplex 2205 Quenched/ annealed at 475°C/air cooled, **C**) Quenched specimen/ annealed at 850°C/ air cooled and **D**) 41Cr4 Stainless steel

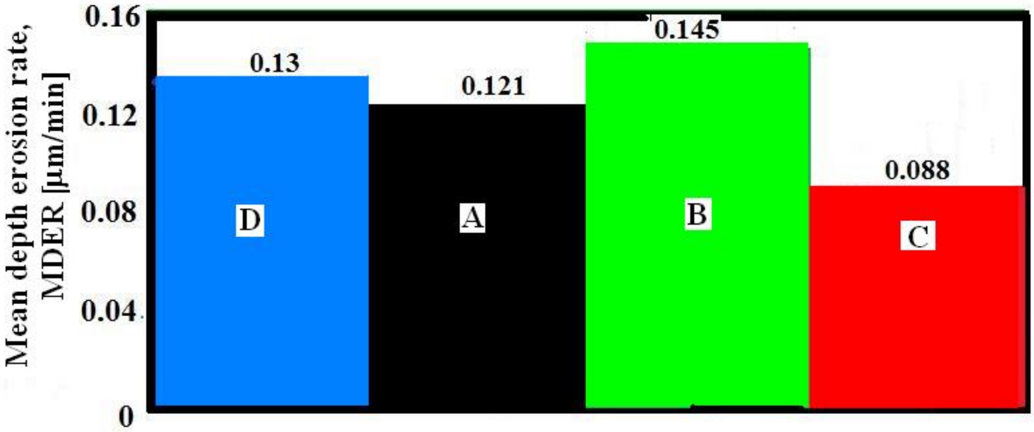


Figure 5. Mean depth erosion rate at final stage (same symbols). Symbols used: **A**) Duplex 2205 Quenched and cooled in water, **B**) Duplex 2205 Quenched/ annealed at 475°C/air cooled, **C**) Quenched specimen/ annealed at 850°C/ air cooled and **D**) 41Cr4 Stainless steel

By comparison with the control specimen 41Cr4 results that all heat treated Duplex steels have good cavitation erosion behavior. The best results were obtained for the heat treatment C (annealed by heating at 850°C and maintained 2 hours at this temperature). Those specimens present also the greatest hardness 362 HV1. The worst results were obtained for the heat treatment B (annealed by heating at 475°C and maintained 4 hours at this temperature) even if the hardness is 330 HV1, greater that of the specimens simply quenched (hardness 275 HV1). This result can be explained by the structure of the specimens, which has increased quantities of ferrite. The specimen C has cavitation erosion enhanced with approximate 10% in comparison to the control specimen (even if the hardness is better with 27%) because of the content of the structural component ferrite.

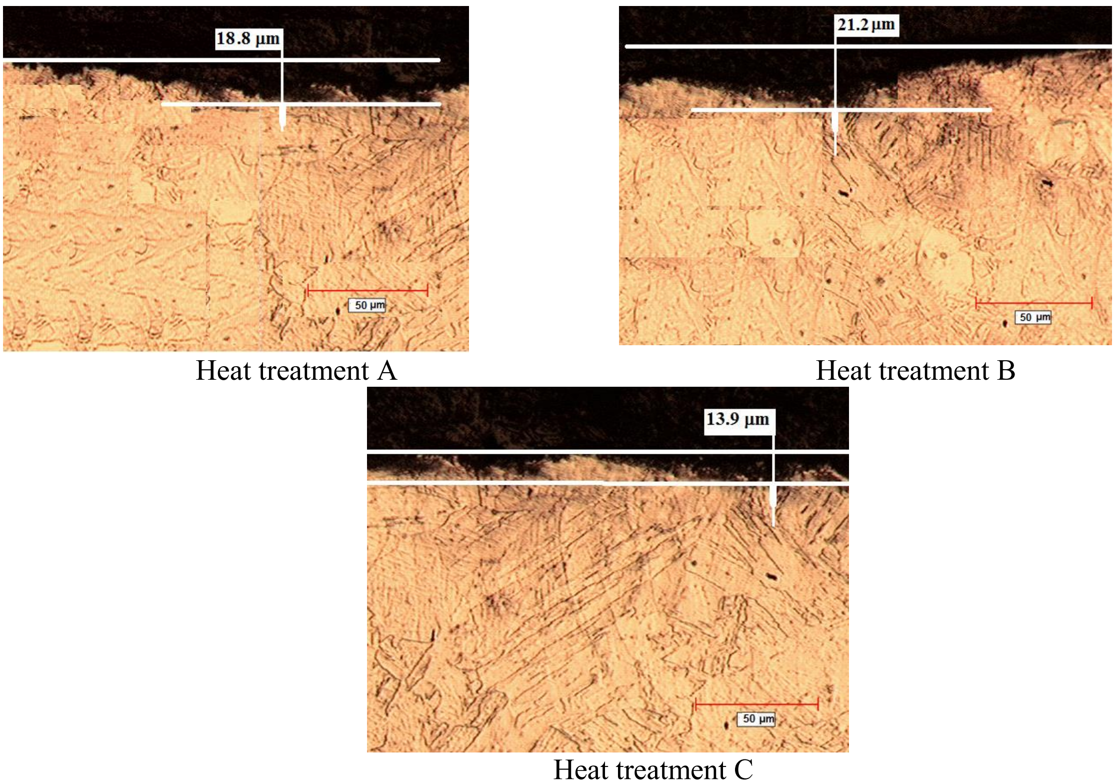


Figure 6. Sections through specimens subjected to final cavitation exposure (8x).

The better resistance of the specimen C is given not only by the greatest hardness but also by the structure in which the austenite is dominant. In Figure 6 are given the microscopic aspects of the eroded area, in the cross sections, near the center of the specimen (zone in which the erosion has its maximum depth). Comparing the maximum erosion depth (from Figure 6) with the mean depth erosion (computed from the lost mass divided with the material density and the specimen area), Figure 4, resulted incredible small differences. When the material is a weak one, the differences increase (in our case till approximate 5.6%). This result can be explained by the fact that in same cases an entire ferrite grain can be expelled. For the resistant materials, the erosion occur by expelling only small parts of the austenite cracked grain, so the difference between MDE and h_{max} is in the range of 1%. The classification of cavitation resistance is the same regardless the procedure adopted (using MDE or h_{max}).

The images in figure 6 present a settlement of the material layer in close vicinity with the layer suffering cavitation erosion. This settlement characterize the materials with excellent cavitation behavior because lead to the reduction of the mean depth erosion rate [1].

4. Conclusions

1. Adequate heat treatments improve cavitation erosion resistance of Duplex stainless steels.
2. The best results are obtained by simultaneously increasing the hardness and improving the structure of the steels. In our case the increase of the alloyed austenite enhanced the behavior of steels annealed at 850°C. The increase of hardness without obtaining the adequate structure can worsen the results.
3. For Duplex steels with reduced cavitation erosion, the differences between the computed MDE and the measured h_{max} are insignificant.

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