THE TRANSFORMATIONS MORPHOLOGY BY CAVITATION EROSION OF GAS NITRITED X2CRNIMON22-5-3 DUPLEX STAINLESS STEEL

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Abstract

In this paper is analyzed, through comparison, the cavitation erosion resistance of Duplex stainless steel, with a microstructure of approx. 50% austenite and 50% ferrite, solution annealed from 1060°C with water cooling and finally nitrided at 520°C for 40 hours in an ammonia environment. The cavitation test results were expressed by variation of mean depth erosion with the attack time and through the correlation between the attacked surface roughness and the erosion resistance.The microstructure investigations, with an optical microscope and electronic scanning microscope, explains the erosion mechanism of the surface layer, by starting and propagation of microcracks.

Keywords: Cavitation erosion, stainless steel, gas nitriding

1. INTRODUCTION

Duplex type austenitic-ferritic stainless steel has potential applications in hydroenergetics, the food industry as well as chemical and pharmaceutical industries. They present an excellent pitting corrosion (PREN > 30), a high yield point, good moldability and cutting machinability. In addition, the high price of Ni in the last years motivated the use of these alloys due to having a reduced content of this element. These alloys became competitive and as a result have increased their number of applications .As some researchers [1,2,3] have reported that these alloys have a lower cavitation erosion resistance than other stainless steels, determined by the presence of ferrite and ferrite/austenite interfaces, the present paper analyzes the role of gas nitriding on the structural transformations occurring in the surface layer that justifies the improvement of cavitation erosion resistance.

2. THE INVESTIGATED MATERIAL. APPLIED TREATMENTS

The material used in the research is represented by the Duplex 2205 stainless steel having the symbol X2CrNiMoN22-5-3 according to the European norm EN 10088, which was purchased from a private firm in Germany. Its chemical composition is presented in **Table 1** and the mechanical characteristics determined at the room temperature are presented in **Table 2**.

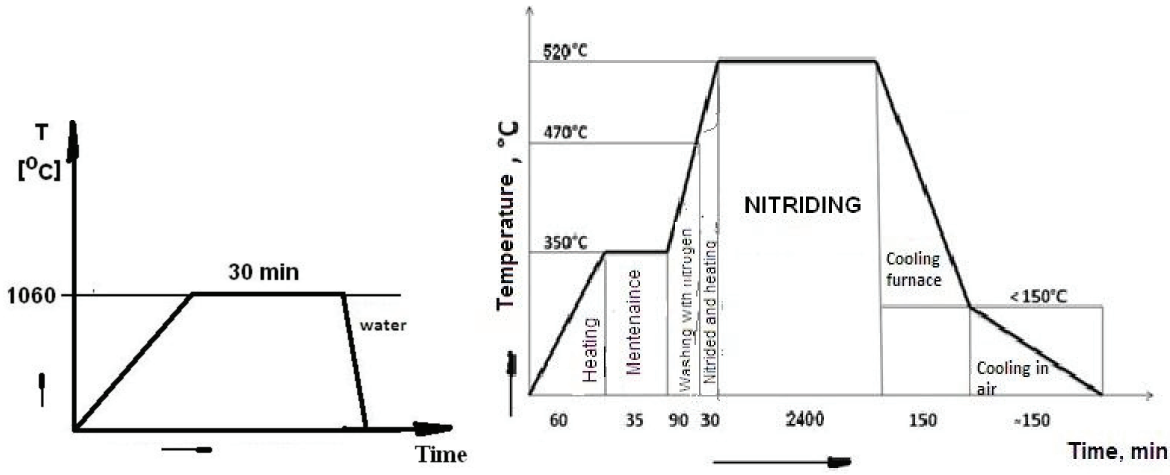
Table 1 Results of chemical analysis

Designation steel	C [%]	Mn [%]	P [%]	S [%]	Si [%]	Ni [%]	Cr [%]	Mo [%]	N [%]	Fe [%]
X2CrNiMoN22-5-3	0.017	1.837	0.024	0.02	0.413	5.019	22.083	2.585	0.1502	rest

Table 2 Mechanical characteristics capable of hardening

Designation steel	Hardness HB (HV1)	Yield $Rp_{0,2}$ (N/mm^2)	Tensile Strength, R_m (N/mm^2)	Elongation at breakA5 (%), Longitudinal
X2CrNiMoN22-5-3	270 (285)	561	728	31

Since the purpose of targeting involved highlighting the effect of gas nitriding on the behaviour of parts operating in cavitation regime, for comparison there were used the results obtained on the same steel heat treated by annealing to be put into solution at 1060 °C, and water cooling. **Fig. 1 a, b** presents heat treatment and thermo chemical ciclogrames applied to the investigated and analysed samples. Measurements of hardness, made in about 10 points, on the surface of the samples (**Table 3**) heat treated by annealing to be put into solution and the gas nitriding measurements led to significant differences. So, for the annealed probes the recorded average value was 285 HV1 and for the gas nitrided surfaces the recorded average value was about 651 HV1. The depth of the nitrided layer was about 0.18 mm and in its microstructure it occurs only in the diffusion area; the chemical combinations area is absent.



a) Ciclograma for solution treatment b) Ciclograma gas nitriding

Fig. 1 The ciclograms samples investigated treatments applied to cavitation erosion

3. APPARATUS AND METHOD FOR INVESTIGATING CAVITATION

The surface degradation of the Duplex steel probes, gas nitrided, was made by cavitation erosion generated in the piezoelectric crystals vibrating apparatus standard T2 [1,5,6], within the Cavitation Laboratory of the “Politehnica” University from Timisoara. For the whole duration of the research, the functional parameters of the apparatus were kept at the design values prescribed by the ASTM G32 norms [5]. The research procedure is that described by the international norms ASTM G32-2010 [4,7]. The preparation of probes and the research program development are those specified to the laboratory [1,5,6]. According to the laboratory, the whole duration of the cavitational attack was 165 minutes, divided in a period of 5 minutes and a period of 10 minutes and 10 periods of 15 minutes each. For each testing period, with the analytical balance ZATCŁCADY, which allows the reading up to 10^{-2} mg, eroded masses were determined, necessary to build the specific curves of cavitation by erosion. They are the basis for establishing the characteristic parameters used in evaluating the resistance of the gas nitrided layer.

3.1. Experimental results and discussions

Evolutionary mode of behaviour and the resistance of the gas nitriding surface, by cavitation erosion are given by the specific curve (1) from **Fig. 2** which shows the variation of the average depth cumulated by the penetration of erosion (MDE) with the duration of the cavitation attack.

The average depth determination corresponding to each intermediary attack period (5, 10 or 15 minutes) was made using the relation [1, 6]:

$$\Delta MDE_i = \frac{4 \cdot \Delta m_i}{\rho \cdot \pi \cdot d_p^2} \quad [mm] \qquad (1)$$

were:
i =1...12- represent the testing period (5 min, 10 min or 15 min),
ΔMDE_i - mean depth erosion generated by cavitation in the Δt_i period.
Δt_i - the cavitation exposure in the period "i"
Δm_i - is the cumulative mass lost during the period i <grams>,
ρ - stainless steel density <grams/mm^3>,
d_p - specimen diameter ($d_p \cong$ 15.8 mm),

Cumulative average depth of erosion penetration, MDE, given in the diagram from **Fig. 2**, was established by the relation:

$$MDE_i = \sum_{i=1}^{i=12} \frac{4 \cdot \Delta m_i}{\rho \cdot \pi \cdot d_p^2} \quad [mm] \qquad (2)$$

Fig. 2 also gives the specific curve of the same steel, subjected to the volumetric heat treatment by annealing to be put into solution and water cooling, according to the ciclogram in **Fig. 1a**. From the comparative analysis of the two curves it can be seen that starting with the 30 minute and up to the test finish, the gas nitriding give to the surface attacked by cavitation o much superior resistance to that obtained by applying the annealing heat treatment to be put into solution.

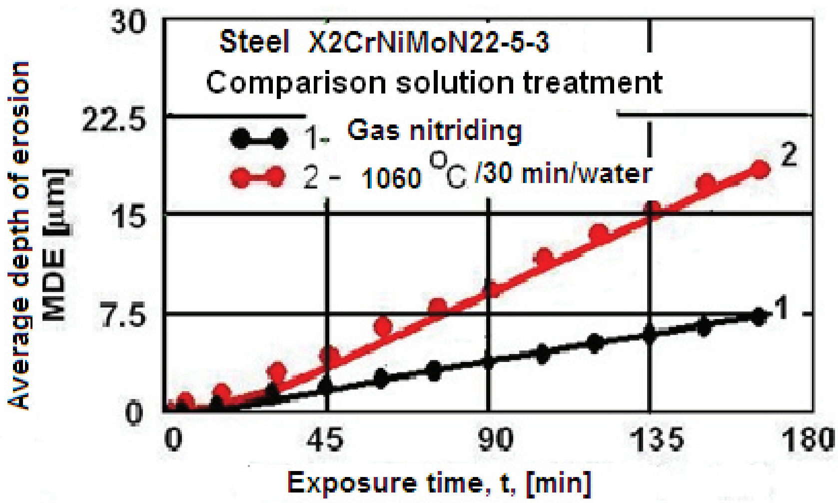


Fig. 2 Variation with depth of penetration during the attack cavitation erosion

According to the ratio of the tangents to the two curves in the interval (30-165 minutes), there comes out that the increase of resistance brought by nitriding is about 2.67 times higher than that made by annealing heat treatment to be put into solution at 1060 °C and water cooling.

The higher resistance to cavitation attack, on the research duration is also confirmed by the images of the eroded surface, presented in **Table 3**, after 90 and 165 minutes of a cavitation attack. It is to note the florist degradation mode of the gas nitrided surface, different of the annealed probe surface that is approximately circular. The explanation is given by the nonhomogeneous hardness dispersion in the nitrided layer, the harder area being harder to destroy by erosion. Random caverns in the nitrided surface are to be also noted in contrast to the degradation of the annealed probe surface, which is more homogenous with uniform distributed pittings on the whole eroded surface. This degradation mode is explained by the morphology of transformations that are produced in the surface structure under the impact of micro jets and shock waves.

Table 3 Images of the eroded surface after different cavitation attack duration

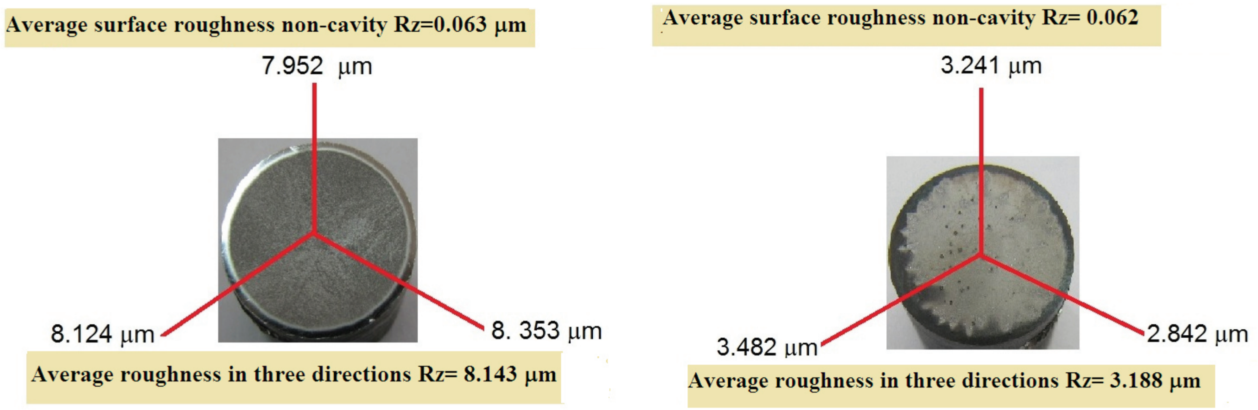
Treatments	Minut attack		
	0	90	165
Nitrided in gas			
Solution annelead			

Resistance to vibratory cavitation, better for the gas nitrided surface, compared with that subjected to the annealing heat treatment to be put into solution, is also confirmed by the average roughness Ra, measured by the Mitutoyo device along three directions (at about 600 one against the other), **Fig. 3**, which is about 2.55 times lower. These roughness measurements associated to the unevenness created by micro jets in the cavitated surface, illustrate the different resistance of diverse area of the surface, as an expression of the structural composition from the beginning of cavitation and modified along the attack.

Fig. 4 compares the characteristic parameters showing the difference between the vibratory cavitation resistance, created by the two treatment technologies (by gas nitriding and anneaing to be put into solution at 1060 oC and water cooling).

The signification of symbols in **Fig. 4** are:

- Parameter maximum roughness Rz was considered equal to the maximum depth of the maximum cavern MDE, on the measurement direction using the Mitutoyo device.
- Rcav represents cavitation resistance given by the inverse value to which it tends to stabilize to the penetration rate of MDER erosion [1].



a) b)

Fig. 3 Roughness values on the cavitation eroded surface for 165 minutes:
a) annealed probes to be put into solution; b) nitrided probes

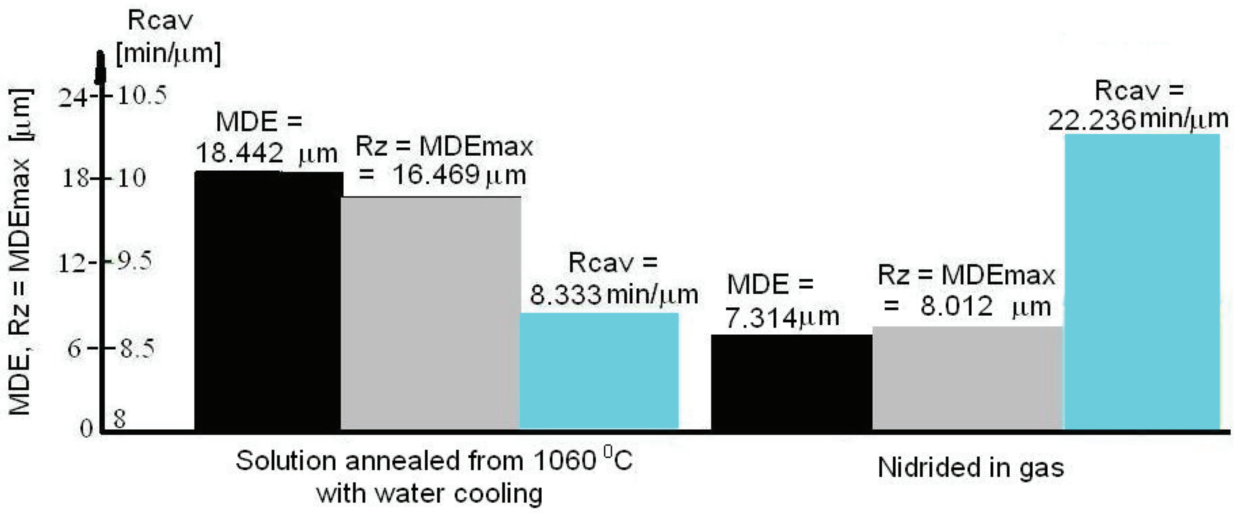


Fig. 4 Comparison after cavitation erosion parameters

According to the Rcav values there results that by gas nitriding the resistance to cavitation erosion increases by about 62 %, and the average penetration depth of erosion is reduced by about 60.3%.

In **Fig. 4** it can be seen that the maximum roughness Rz (respectively the maximum depth MDE max) of probes annealed to be put into solution is inferior to the average MDE, as in the case of the gas nitrided probe the situation is reversed. It is a natural situation, as in the case of the annealed to be put into solution probe the deepest cavern in the cavitated surface was not found on the measurement direction. In the case of the gas nitrided probe a cavern was found having a greater depth than the average calculated with the relation (2). The two situations show the complexity of the mechanism producing erosions in different areas of the surface, under the impact of micro jets and shock waves generated by the implosion of cavitation bubbles. The micrographic images in **Figs. 5 and 6** show that the degradation of the nitrided surface are primed and developed preponderantly on the interfaces between ferrite and austenite, but with a more reduced intensity, smaller cavities in sizes, respectively as compared with the structural state obtained by annealing to be put into solution.

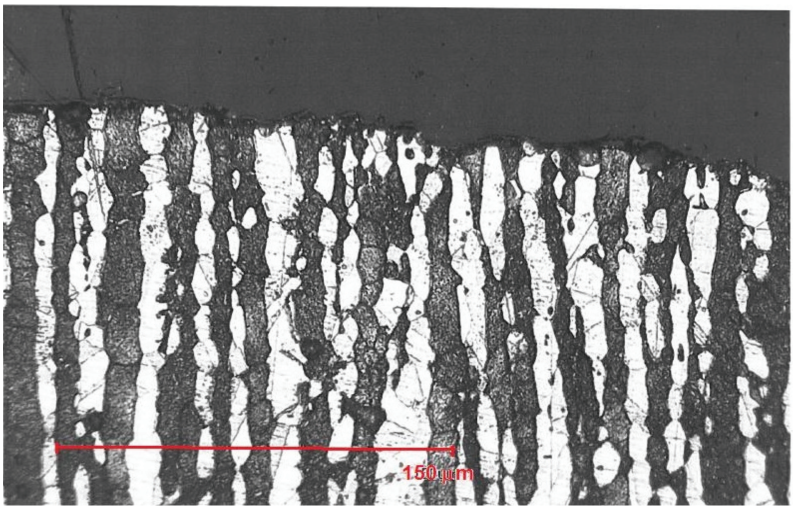
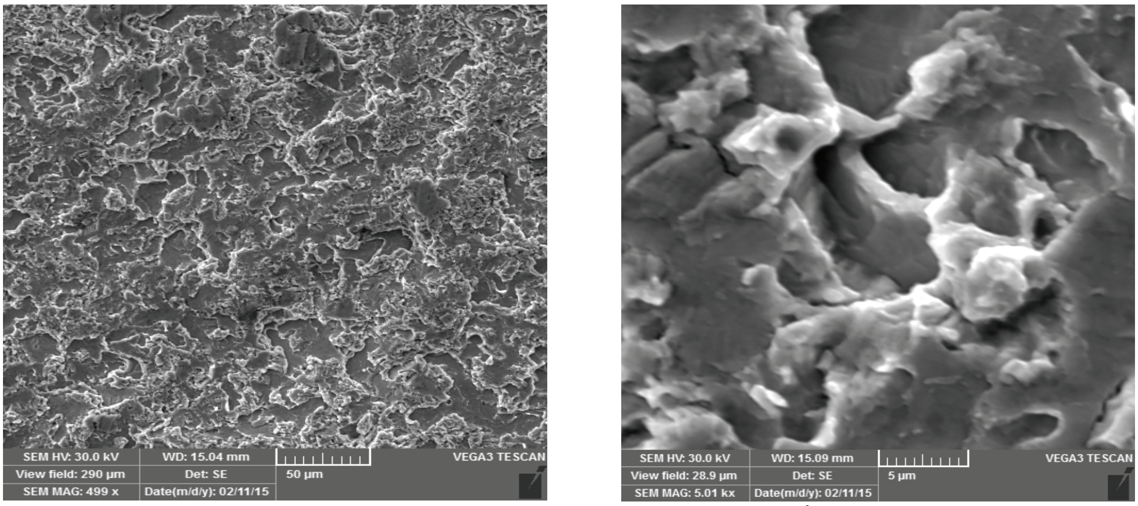


Fig. 5 Microstructure of a longitudinal section through the cavity for 165 min



- a - - b -

Fig. 6 Nitrided surface topography and cavity for 165min: a) x 500; b) x 5000

4. CONCLUSIONS

The nitriding thermo chemical treatment applied to the Duplex stainless steel parts determines an increase of the cavitation erosion resistance (2.7 times) and a decrease in the average penetration depth of the erosion, MDE (about 2.5 times), respectively. The absence of the chemical combinations area in the nitrided layer and in the diffusion area, that assures the surface hardness, leads to the decrease in the degradation rate of the interface between ferrite and austenite.

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