CAVITATION EROSION BEHAVIOR OF SOME GAS NITRATED STEELS

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Abstract: Older researches, conducted by Garcia and Hammitt (published in 1960) showed that hardness is an important factor in increasing the resistance of the surfaces exposed to cavitation erosion. As a result, in present more and more researches are oriented in increasing the hardness of areas subjected to cavitation flows. An excellent procedure is represented by the use of thermochemical treatments through which is realized a thin but very hard layer, with an increased resistance to cavitation implosions and subsequently conducting to a substantial increase of the running time between two consecutive repair works. In step with these research direction are inscribed also the researches presented in the present work. The researches were carried out in the Timisoara Polytechnic University Cavitation Laboratory, on a cavitation erosion device with piezoelectric crystals. There were used three different types of steels (two of them stainless steels and the third an alloyed one) gas nitrated. The comparison between these three types of steels show that the cavitation erosion resistance depends essentially on the layer hardness and the solution can ban be used for machine details having the shape and dimension which allow the use of the treatment both for the manufacturing and repair works proceedings.

Key words: cavitation erosion, vibratory cavitation device, gas nitration, steel, mean depth erosion

1. INTRODUCTION

The thermochemical treatments are enrichment processes of a thin superficial layer with some chemical element (frequently C, N, Br, Al), through the atomic diffusion form an exterior environment found at high temperature. They consist in heating the machine parts at a given temperature, in a solid, liquid or gaseous environment which releases easily the enrichment atoms followed by the maintenance at a set temperature and finally by a controlled cooling [5], [7]. In comparison with other heat treatment the thermochemical one determines in the superficial layers both the modification of the structure and the chemical composition. The machine details which can be subjected to this procedure have a large diversity of shapes and dimensions.

From the multiple advantages given by the thermochemical treatments [5], [7] it can be enumerated:
- increase of the superficial hardness and implicitly wear resistance;
- increase of fatigue resistance;
- increasing resistance against the layer pulling;
- keeping high values of ductility and tenacity characteristic which allow the inner side to resist to the dynamic operating commands
- increasing the running service before cavitation erosions repair works

As process, gas nitration can be applied both for steel and cast irons. As a result of nitration the superficial layer, with a thickness of the order of tenth of millimeters and with a hardness till 1100 HV, has a great resistance to contact wear, erosion and fatigue as well as very good capacity to take over the chokes [5]; qualities extremely important for the surfaces subjected to cavitation (retaining rings for butterfly valves, drawers, valves, hydraulic devices for control, distribution and adjustment). Another great advantage of gas nitration is represented by keeping the good mechanical characteristics of the core (great tenacity), extremely important for the details subjected to great mechanical stresses besides the cavitation flow.

2. EXPERIMENTAL RESEARCHES

2.1. Researched materials

The researched materials take parts from the stainless and high alloyed steels suited to gas nitration treatment. Their chemical composition and the mechanical properties were carefully determined in the Timisoara Polytechnic University laboratories for Material Strength and Material Sciences where have been obtained the following results:
- The stainless steel X5CrNiMo17-12-2 (BS EN10088-2; No.1.4401), with a preponderant austenite structure (approximate 98% austenite and 2% ferrite): 0.034% C, 16.515% Cr, 11.105% Ni, 0.689% Si, 1.591% Mn, 0.029% P, 0.015% S, 1.206% Mo, 0.09% N, the rest being iron; Rm = 566 MPa, Rp0.2 = 241 MPa, Brinell Hardness (HB) = 197daN/mm².
- The stainless duplex steel X2CrNiN 23-4 (BS EN10088-2; no.1.4362), with a duplex structure (approximate 40 % austenite and 60 % ferrite): 0.026% C, 22.51% Cr, 5.12% Ni, 0.86% Si, 1.82% Mn, 0.031% P, 0.012% S, 0.47% Mo, 0.18% N, 0.5

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% Cu, the rest being iron; Rm = 710 MPa, Rp0.2 = 550 MPa, Brinell Hardness (HB) = 290 daN/mm².

The stainless alloyed steel 42CrMo4 (BS EN 10250), with the structure formed from proeutectoid ferrite and bainite: 0.039%C, 1.15%Cr, 0.58%Ni, 0.35%Si, 0.72%Mn, 0.21%P, 0.27%S, 0.24%Mo, the rest being iron; Rm = 1100 MPa, Rp0.2 = 730 MPa, Brinell hardness (HB) = 310 daN/mm².

The structure for stainless steels were established using the Schäffler diagram [1], [2], [6], [8], and that of the alloyed steel through metallographic analyze.

2.2. Heat treatment procedure

The last century experience show that the stainless steels, as the result of structural and mechanical characteristics are materials with good cavitation erosions qualities [1], [6], [8]. Recent researches show that by using thermochemical treatments the cavitation erosion resistance may be increased. That is way we subjected the specimens to gas nitration. The procedure was applied following the diagram presented in fig. 1 and consisted principally in the heating during 40 hours in a furnace with controlled nitrogen atmosphere, at 570°C (for the austenitic and duplex stainless steels), respectively at 530°C (for the alloyed steel 42CrMo4). Through this procedure the nitrogen found in atomic state in the furnace atmosphere penetrated through diffusion in the superficial layers of the specimens. The combination with iron and alloying elements giving rise to nitrides. The cooling was made in the treatment furnace till approximate 150°C and after that continued in air. After gas nitration the specimen surfaces exposed to cavitation were processed by fine grinding till the roughness Ra = 3.2 µm being lost from the layer approximate 0.01…0.02 mm. Those losses does not influence the cavitation erosion process.

To know the hardness variation in the nitrated layer there have been made measurements of hardness, according to the scheme presented in fig. 2. The results are presented in fig. 3 and show the variation of hardness in the cross section. The initial hardness has increased values. The explanation is the chromium presence as principal alloying element and a very good nitride builder, which determines a pronounced increase of the hardness, till 900 – 905 HV0.5 for the austenitic stainless steel X5CrNiMo17-12-2, till 600-610 HV0.5 for the duplex steel X2CrNiN 23-4 and 850-860 HV0.3 for the alloyed steel 42CrMo4. The depth of the nitrated layer, being defined in conformity with the literature data [1], [5], as the distance from the surface till at the point with a hardness overcoming with 50 HV those of the core and has for the researched steels values between 0.1-0.4 mm, depending the steel structure.

The chemical analyses of the treated layers put in evidence the following nitride types:

- austenitic stainless steel: X5CrNiMo17-12-2: Mo₂N, CrN, Fe₂N; MoN, CrN, Fe₂N;
- duplex steel X2CrNiN 23-4;
- alloyed steel 42CrMo4: MoN, CrN, Fe₂N.

The density values obtained for the nitrated layers are:

- austenitic stainless steel X5CrNiMo17-12-2: ρ = 7.7 g/cm³;
- duplex steel X2CrNiN 23-4: ρ = 7.79 g/cm³;
- alloyed steel 42CrMo4 ρ = 7.77 g/cm³.

Fig.1. Gas nitration thermochemical treatment diagram

Fig.2. Scheme of the hardness measurement for the nitrated layer

a) austenitic stainless steel X5CrNiMo17-12-2

b) duplex stainless steel X2CrNiN 23-4
2.3 Cavitation erosion test results and discussions

The researches regarding the behavior and the resistance against cavitation erosion of the layer obtained through nitration was realized in the Timisoara Polytechnic University Laboratory for Cavitation using a vibratory device with piezoelectric crystals. For each type of material were tested three specimens. The procedures of specimen preparation, data recording, processing of results was in line with the laboratory standard and in concordance with the indication of ASTM G32-2010 Standards.

Kept constants over the entire duration of the tests, the functional parameters of the device were: power 500 W, vibration frequency 20000 ± 200 Hz, vibration amplitude 50 μm, alimentation voltage 220 V/50 Hz. The specimen diameter was 15.9 ± 0.05 mm, the used liquid was double distilled water with the temperature of 22±1ºC.

In fig. 4 are given the resulted experimental values and the specific approximation curves for mean depth erosion (MDE) and mean dept erosion rate (MDER). For the approximation curves were used the analytical relationships established within the laboratory. The values of the experimental points are means of the results for the three specimens tested from each material.

As can be seen from fig.4 the scatter of the experimental obtained values from the analytic mediation curves are very small. The explanation consists in the fact that the hardness of the cavitation exposed surface is uniformly distributed.

Also, it is to be observed that from the curves MDE(t), presented in fig.4a, the austenitic stainless steel has the same resistance as the high alloyed steel, but the best cavitation erosion behavior (see fig. 4b) from the evolutions of the curves MDER(t) and from the parameters MDERs (for which the erosion velocities obtain stable values) the best cavitation behavior is given by the austenitic steel X5CrNiMo17-12-2, succeeded by the high alloyed steel 42CrMo4. Those differences are given from the hardness values of the superficial layer (see fig. 3).

To highlight the increase given by nitration in fig.5 is presented a comparison between the three nitrated specimens against the results for the best untreated steel (the stainless steel X5CrNiMo17-2-2 in annealed condition).
From the two diagrams presented in fig. 5 it results that by the nitration procedure there were reduced both the mean depth erosion (MDE) and the mean depth erosion rate (MDER). The maximum values of the erosion depth (MDE1…MDE2 –fig. 4a) show that at the end of tests there was not overcame the thickness of the nitrated layers (there have the thickness of about 0.1 - 0.4 mm). For a better understanding of the erosion evolution in table 1 are presented the macroscopic images, at for distinct exposure to cavitation, realized with a photo apparatus Canon Power with great resolution (16 pixels). In fig. 6 are given images obtained through optical and electronic-scan microscopy.

Table 1. Macro images with the cavitation erosion evolution in the nitrated layer

<table>
<thead>
<tr>
<th>Nitrated steel</th>
<th>Duration of the cavitation erosion attack [minutes]</th>
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<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>X5CrNiMo17-12-2</td>
<td></td>
</tr>
<tr>
<td>X2CrNiN 23-4</td>
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<tr>
<td>42CrMo4</td>
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The images in Table 1 obtained at the end of tests (165 minutes), show that the erosion is extended on the whole nitrated area exposed to cavitation. The floral forms, easy to be observed especially on the X5CrNiMo17-12-2 steel specimens, in the middle of the exposure times, are effects of material resistance to the micro jets impacts created by the cavitation bubble implosions.

The micrographic images presented in fig. 6 show that:

- **for the austenitic stainless steel** the inner core has a microstructure composed from austenite with annealing twin a certain proportion of δ ferrite and small quantities of carbides, molybdenum, chromium and iron ferrite. The erosion of the nitrated specimens, having a great hardness is slow and uniform;

- **for duplex stainless steel** the erosion of the nitrated surface is initiated and developed especially on the interfaces between ferrite and austenite but with a reduced intensity, the expelled particles having small dimensions. The cracks setting in occur at nitrated particles especially in the separation surfaces between their limits. The microstructure with high hardness even in the edging restricted the erosion which remains with very fine cracks without deep or great craters;

- **for the high alloyed steel** the microstructure of the superficial layer formed by simple and complex nitrates, dispersed in a solid solution enriched in nitrogen preventing the displacements along the sliding planes of the crystal as a result of the increase of the mechanical parameters, especially the hardness. The differences between the MDE values in fig. 4a between the three nitrated layers confirms the inhibitor effect of the hardness against cavitation erosion.

The eroded surface analyze, even by eyes, show that surface the values of the erosions can be evaluated using the roughness parameters. Using for this purpose the Mitutoyo SJ 210 device, fig. 7, for one specimen of each type of material, there were realized profile records of the cavitation eroded surface (this operation was done at Timisoara National Research –Development Institute for
Welding and Material Testing which is the owner of the Mitutoyo device.

In the figures 9 are given the roughness profile recorded for a length of 4 mm, in the central zones, in conformity with fig. 8, on which subsequently was realized the axial section of the specimen and were obtained the photos presented in Fig. 6. It resulted that the $R_z$ parameter value obtained from the measured profile of the roughness for the three eroded specimens (7.13 $\mu$m for the stainless austenitic steel; 7.92 $\mu$m for the stainless duplex steel and 7.21 $\mu$m for the high alloyed steel), are a little greater than the MDE values (6.789 $\mu$m; 7.425 $\mu$m and 6.899 $\mu$m). The differences are naturally because the Mitutoyo are directly measured dimensions while MDE are mean values computed from the mass loss for three specimens. On the other hand, this is a motive to a bigger confidence in the MDE measurements made in conformity to the ASTM Standard [4], [9]. Some differences between $R_z$ and the maximum depth measured and indicated in fig. 4a, are due to the fact that the image was taken from another zone that those measured with the Mitutoyo device.

3. CONCLUSIONS

The use of the gas nitrating procedure, compared with the annealed state of the steel X5CrNiMo17-12-2, due to the nitrates formation in the superficial layer, favors the increase of the resistance at cavitation erosion as the result of the hardness increase.

The small differences between the parameters MDE (for the final exposure time) and MDERs depends in great measure on the values of the hardness and the formed nitrates than upon the steel structure.

The small differences occurring between the cavitation erosion parameters MDE and the roughness parameter $R_z$ are normal because of the great differences in the measuring procedures. The aspects of the surface with cavitation erosions put into evidence preferential erosion, strictly depending on the layer type.

The microstructure resulted after the nitration procedure, having an increased hardness suffer smaller and lent erosion.

Even if the nitration procedure implies supplementary costs it is justified by the increase of running duration and the reduction of the repair time and costs in the working periods of the hydraulic devices.

REFERENCES


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