COLD WORK HARDENING AND RESISTANCE TO CAVITATION EROSION OF THE AUSTENITIC STAINLESS STEELS WITH VARYING PROPORTIONS OF DELTA FERRITE

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Abstract

The paper analyzes, comparative, the resistance to the cavitation erosion for the X5CrNi18-10 classic steel, with that provided by two another steels, processed experimental, with approx. 0.1 % C, 24% Cr, 18 %, approx. 10% Ni and wich was cold work hardened by vibro rolling. Cavitation tests were performed on a vibrating device with piezoelectric crystal, in the Laboratory of Hydraulic Machines in Timisoara (LMHT), determining the characteristic curves of the variation in time of the mean depth erosion, MDE(t) and mean depth erosion rate, MDER(t). By mechanical tests and by metallographic investigation is warranted increased erosion resistance after cold plastic deformation and minimization the effect of reduction its to higher proportions of delta ferrite, due to higher chromium content. Conclusions detached, after the investigations, serve designers and processors by stainless steel to chemical composition optimization and to manufacturing processes, in order to increase the lifetime of hydromechanical equipment, such as hydraulic turbines, pumps and throttle butterfly valves on pipelines forced, etc.

Keywords: mechanical hardening, characteristic curves, resistance to cavitation, microstructure, chemical elements, mechanical properties

1. INTRODUCTION

The cavitation erosion of hydraulic rotor blades and continues to be one of the difficult problems facing researchers and users of hydromechanical equipment. Numerous research institutes around the world are looking for solutions to reduce the degradation of various types of surface corrosion and wear. Among them are found those aimed at developing new austenitic stainless steel with microstructure predominantly to withstand the impact of cavitation bubbles which implode microjets generated by adjacent solid surfaces. Their advantage in the manufacture of components such as valves butterfly valves, turbine blades and rotors and hydraulic pumps, welding reshuffle is available for areas affected by cavitation erosion. This paper highlights the role of cumulative carbon (austenite forming element) and chromium (ferrite forming element), and the cold hardening by cold inhibition of degradation by erosion cavitation, which is reducing material losses from the solid surface.

2. MATERIALS INVESTIGATED

The materials investigated, Tables 1 and 2 are part of stainless steel, designed on the basis of lessons learned from the operation of hydraulic machines, on the chemical composition and the mechanical characteristics. They were built by professionals molded recipes Expertise Center of Special Materials, University Politehnica of Bucharest and molded by SC. Prod SRL Bucuresti. To identify them in the analysis, we use notations which take account of the ratio of the proportions of austenite and ferrite δ set after Scäffler diagram [2], [3] (see Table 1). Both developed experimental steels were subjected to homogenization anneal before being mechanically hardened by vibrorolling (Table 2). Class steel, X5CrNi18 - 10 was subjected to solution treatment at 1050°C with cooling water. For these conditions the values obtained structural mechanical properties shown in table 3.
Table 1. Chemical elements. Microstructural constitution

<table>
<thead>
<tr>
<th>Steel symbol</th>
<th>Chemical elements, structural constituents, [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>98A/2F</td>
<td>0.097</td>
</tr>
<tr>
<td>81A/19F</td>
<td>0.118</td>
</tr>
<tr>
<td>X5CrNi18-10</td>
<td>0.036</td>
</tr>
</tbody>
</table>

Table 2. Vibrorolling effect of the workpiece thickness

<table>
<thead>
<tr>
<th>Steel symbol</th>
<th>Thickness Before hardening</th>
<th>Thickness After hardening</th>
<th>Reduction mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>98A/2F</td>
<td>30.1</td>
<td>28.4</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>29.8</td>
<td>27.5</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>29.6</td>
<td>27.8</td>
<td>1.8</td>
</tr>
<tr>
<td>81A/19F</td>
<td>30.2</td>
<td>28.1</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>29.5</td>
<td>27.7</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>29.8</td>
<td>27.8</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Table 3. The mechanical properties of the examined steels

<table>
<thead>
<tr>
<th>Steel symbol</th>
<th>Rm [N/mm$^2$]</th>
<th>Rp$_{0.2}$ [N/mm$^2$]</th>
<th>HRC</th>
<th>A5 [%]</th>
<th>Structural state</th>
</tr>
</thead>
<tbody>
<tr>
<td>98A/2F</td>
<td>1235</td>
<td>934</td>
<td>38</td>
<td>8</td>
<td>Mechanically hardened through vibrorolling in 3 minutes. with a force of 40,000 N;</td>
</tr>
<tr>
<td>81A/19F</td>
<td>1080</td>
<td>801</td>
<td>30</td>
<td>9</td>
<td>Mechanically hardened through vibrorolling in 3 minutes. with a force of 40,000 N;</td>
</tr>
<tr>
<td>X5CrNi18-10</td>
<td>527</td>
<td>269</td>
<td>233 HB</td>
<td>24</td>
<td>Annealing of sample</td>
</tr>
</tbody>
</table>

It is noted that the first two steel are having a carbon content of about 0.1%, and at the end, very low as 0.036%. This is important because studies show that a low carbon content provides good weldability [1], [2]. As expected, in Table 3 shows that steels with higher carbon content have a higher level of mechanical resistance characteristics. It is also noted that two steels are close to the nickel and chromium contents, but different proportions of Cre and Nie, due to the presence of other alloying elements that result in the difference between the amounts of austenite and $\delta$ ferrite (98/2 and 93/7).

3. APPARATUS AND METHOD RESEARCH

Cavitation, which were exposed specimens taken from the blanks so processed was generated piezocermaic crystal dildo machine in the Cavitation Laboratory, Politehnica University of Timisoara [2], [4], [6]. Test procedure complies with regulatory requirements ASTM G32-2010 [7] and custom laboratory established over 70 years of experience [2], [4], [6].

3.1. Experimental Results. The resistance to cavitation

Based on the mass loss were determined cumulative average depth of penetration of erosion, MDE and the average penetration rate of erosion, MDER, attack each interim period, the total duration of 165 minutes according to laboratory procedure [3], [4].
Fig. 1 illustrates the experimental points and curves of cavitation erosion specific MDE (t) and MDER (t) approximation, which provides an insight into the behavior, the three steels investigated during vibratory cavitation attack.

**Evaluation of behavior and resistance to cavitation**, based on experimental points and curve approximation:

1. **98A/2F steel, curve 1.** After approximately progress curves and experimental points after their dispersion curves to analytical Figure 1 shows that surface erosion cavitation occurs uniformly attacked with a speed approximately constant between 60-165 minutes. Deviation higher speed experimental at 120 minutes, we consider as natural and normal processes cavitation complexity [2], [4], [6] because it consists speeds of between 60-105 minutes, Figure 2, express and produce cracks (in the interim period), merged and allowed removal of larger amounts of material, most likely δ ferrite. Also, the band dispersion of the curve to MDER (t), 1B. relatively low, voice and high degree of compaction, hardening of surface cavities that lead to stabilization of erosion rates at the maximum, MDERs = 4.035 μm / hour.

2. **81A/19F steel, curve 2.** The diagram shown in Fig. 1 shows the cumulative mass loss increased approximately linearly reduced losses within 15-60 minutes. However, the data shown in FIG. 2b shows that the losses are the most important in the period of 60-105 minutes. The explanation is given by the union of cracks generated in the first part of the attack cavitation in δ ferrite grains, ie the boundaries between grains of δ ferrite and austenite. Microjets impact and shock waves with these grains of inter - and transcristaline break and cause expulsion. Most likely, the behavior of the period 60-105 minutes δ ferrite is generated in microstructure , the proportion of cca.19 % (constituent that destroys most easily by cavitation). After 120 minutes , cavitation erosion is a relatively constant evolution , material suffering both plastic deformation and material losses, erosion rate stabilizes at value MDERs = 4.935 μm / hour.

3. **Steel X5CrNi18-10, curve 3.** Approximate shape and dispersion curves to these data points, the average depth of penetration, fig. 1 and the mean depth of penetration rate, fig. 1b, resulting in the following findings:

- After 60 minutes of cumulative mass loss cavitation attack has a linear variation (loss approximately constant intermediate periods of attack);
- Approximately symmetrical dispersion curve data points to approximate the average speed of erosion after 60 minutes shows that erosion is uniform with speed tends to stabilize at MDERs value = 11.718 μm / hour;
- From the first minutes of the attack cavitation are significant losses, which are due primarily δ ferrite, which destroys most easily under the impact of the shock waves and microjets generated cavitation bubbles to implode.

We believe that this method of dispersion of experimental points and curves approximate evolution is caused by low levels of mechanical resistance characteristics, H, Rm and Rp0.2, Table 2. The slight decrease in the erosion rate, the amount of stabilization, the surface layer hardening due to the compaction phenomenon characteristic of cavitation process.

However, in Figure 1, it is seen that steels and 81A/19F 98A/2F resistance behavior and have about the same, although varying proportions of austenite and δ ferrite. Reported differences in accumulation period (up to 75 minutes) are insignificant, being within the tolerances of the specific complex cavitation processes [1], [4], [5]. This is the expression of complex behavior mechanism of cavitation erosion predominantly austenitic steels microstructure.

We appreciate that behavior and reduced cavitation resistance of steel X5CrNi18 -10, with a significant percentage of austenite (93 %) is due to lower carbon content (0.036 %) that also reduce the level of mechanical strength. However, we believe that although the higher percentage of carbon in these cases helps to increase resistance to cavitation, low carbon steels (0.036 %) are desirable components of hydraulic valves and butterfly valves, due to their availability, higher welding operations quite common during periods of current and capital repairs.

4. MICROSTRUCTURE ERODED BY CAVITATION. PHENOMENOLOGY DEGRADATION

In Figures 2-4 are shown images of macro-and micro-cavity surface samples for 165 minutes which show the topography of eroded surfaces, crack propagation and fracture mode.
The main observations drawn from these investigations are:

Steel 98A/2F - cavitation erosion on areas analyzed present a mixed look of the front propagation through intergranular cracks and cleavage planes.

Breaking is a ductile character 81A/19F steel - surface appeal voids with diameters larger than 200 μm, highlighting the appearance of intergranular corrosion. Also zonal lines appear twinned, of intergranular cracks and corrosion on many points macles lines. Rupture propagates both transcristaline and intergranular.
Steel X5CrNi18-10 - large voids analyzed surfaces with cracks and cleavage planes. Tear propagation occurs along the slide.

4. CONCLUSIONS

Closure of Cr content from 18 to 24% in austenitic stainless steels of approx. 0.1 % of C and 10% Ni to passivation and an increase in oxidative stability is manifested by an increase in the proportion of δ ferrite in the microstructure to about 20 %.

The effect of mechanical work-hardening obtained by vibrorolling causes a significant improvement in the characteristics of mechanical strength and mitigates the tendency to reduce the cavitation erosion resistance of the delta ferrite.

Classical austenitic steel with 0.05 % C, 18 % Cr and 10 % Ni subjected to annealing heat treatment for release of the stabilizer solution has a speed of about cavitation erosion. 2.5-fold higher than in the two experimental steels, due to lower its mechanical strength (the limit of the flow is approx. 3 times less).

LITERATURE