A METHOD FOR TESTING PIPE STEELS UNDER THE CONDITIONS OF SULFIDE STRESS CRACKING

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We propose a testing method for the evaluation of the threshold crack resistance \( K_{\text{Issc}} \) of pipe steels under the conditions of sulfide stress corrosion cracking. The values of \( K_{\text{Issc}} \) are determined for various casing tubes made of different types of steel after heat treatment.

The presence of hydrogen sulfide in well fluids imposes severe restrictions on the use of high-strength pipe steels due to the phenomenon of sulfide stress cracking (SSC). The appropriate selection of materials for wells is determined by their mechanical properties and strongly depends on the corrosion cracking behavior of metals in environments expected in service. The required knowledge is partially accumulated in the form of in-service experience but, mainly, by analyzing the results of appropriate laboratory testing in the stage of design.

The laboratory investigation of the performance of materials for acid-service applications is largely based on the use of standard testing methods, such as the methods recommended by NACE [1]. One of these methods based on the fracture-mechanics approach (NACE Standard TM0177-96, Method D: Standard Double-Cantilever-Beam Test [1]) is usually applied to check the value of \( K_{\text{Issc}} \) below which the material operates safely and reliably. Method D recommends to use wedge-loaded double-cantilever beam (DCB) specimens. In this case, the equilibrium wedge load \( P \) for a crack arrested in an \( \text{H}_2\text{S} \) environment is determined by the abrupt change in the slope of the load–displacement curve plotted for specimens held in acid environments. Unfortunately, the values of \( P \) are usually characterized by measurement errors resulting in a wide spread in the values of \( K_{\text{Issc}} \) [2, 3].

In the present work, we propose a modification of the TM0177-96 testing method for \( K_{\text{Issc}} \) which eliminates the necessity of measuring \( P \). We study steels for casing tubes with different microstructures and levels of strength.

Materials and Experimental Procedure

Six as-received casing tubes were used in this investigation. The tubes were made of 45 steel (0.45C), 30G2 steel (0.30C) (Russian grades), and SM90-SSU and C75-1 API (American Petroleum Institute) low-alloy steels. The tubes made of 30G2 steel were prepared by using different modes of heat treatment to get three levels of strength: 30G2(1), 30G2(2), and 30G2(3). The sizes of the tubes, modes of heat treatment, and mechanical properties are summarized in Table 1. The corrosion tests were carried out in a standard NACE aqueous solution [1]: 0.5% of acetic acid and 5% of sodium chloride periodically saturated with \( \text{H}_2\text{S} \) (pH 3.1 ± 0.2) at room temperature.

The DCB specimens were used to determine the value of \( K_{\text{Issc}} \) (Fig. 1). The procedure of testing was described in [4] and included in the NACE Standard TM0177-96 (Method D) [1]. The specimens were wedge-loaded and held in the NACE solution for 360–720 h. After removal from the testing environment, the values of the equilibrium load \( P \) and equilibrium crack length \( a \) were found and used for the evaluation of \( K_{\text{Issc}} \) [1, 4], namely,

\[
K_{\text{Issc}} = \frac{2\sqrt{3} Pa(1 + cha^{-1})}{Bh^{3/2}} \left( \frac{B}{B_n} \right)^{1/\sqrt{3}} ,
\]

where \( h, B, \) and \( B_n \) are the dimensions indicated in Fig. 1 and \( c = 0.687 \).
Table 1. Mechanical Properties of the Investigated Casing Steels

<table>
<thead>
<tr>
<th>No.</th>
<th>Size of the tube, mm</th>
<th>Steel grade</th>
<th>Heat treatment</th>
<th>Yield strength, MPa</th>
<th>Tensile strength, MPa</th>
<th>Elongation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>140 × 9.2</td>
<td>St. 45</td>
<td>N</td>
<td>476</td>
<td>704</td>
<td>23.2</td>
</tr>
<tr>
<td>2.</td>
<td>127 × 9.2</td>
<td>30G2(1)</td>
<td>N</td>
<td>476</td>
<td>726</td>
<td>20.4</td>
</tr>
<tr>
<td>3.</td>
<td>140 × 9.2</td>
<td>30G2(2)</td>
<td>QT</td>
<td>685</td>
<td>882</td>
<td>22.4</td>
</tr>
<tr>
<td>4.</td>
<td>114 × 8.6</td>
<td>30G2(3)</td>
<td>QT</td>
<td>736</td>
<td>864</td>
<td>18.0</td>
</tr>
<tr>
<td>5.</td>
<td>127 × 12.7</td>
<td>SM90-SSU</td>
<td>QT</td>
<td>693</td>
<td>796</td>
<td>20.0</td>
</tr>
<tr>
<td>6.</td>
<td>273 × 8.9</td>
<td>C75-1</td>
<td>N</td>
<td>513</td>
<td>805</td>
<td>21.2</td>
</tr>
</tbody>
</table>

*Note:* N stands for normalization and QT means quenching followed by tempering.

The experimental practice shows that direct measurements of \( P \) are not sufficiently accurate [2, 3]. First, this quantity is characterized by a wide spread of values. Moreover, it was shown that some load–deflection curves used to estimate the value of \( P \) are formed incorrectly either due to the existence of a gap between a yoke and a hole (Fig. 2a) or due to the appearance of adhesive forces between the wedge and DCB arms (Fig. 2b). Sometimes, the load–deflection curves do not have a sharp break in the slope (Fig. 2c) used to determine the value of \( P \).

To analyze the accuracy of measurements of \( P \), some specimens were loaded in a tensile-testing machine up to a recorded load \( P_0 \). The displacements of arms \( \delta \) were fixed by the wedge. After a short period of time (24 or 36 h but prior to the onset of crack propagation), the tests in the NACE solution were interrupted and the values of \( P \) were estimated according to the load–displacement curve. These values were usually higher than \( P_0 \) (sometimes by up to 30%).

To avoid errors in the load–deflection curve resulting from the test measurements of \( P \), we also used another procedure for the evaluation of \( K_{issc} \) based on the second equation of Heady [4]

\[
K_{issc} = A a \delta^{3/2} \left[ \frac{3.464a + 2.38h}{a^4 + 2.061ha^3 + 1.416h^2a^2} \right] \left[ \frac{B}{B_n} \right]^{1/3},
\]