Influence of Stress Concentrator Shape and Testing Temperature on Impact Bending Fracture of 17MnSi Pipe Steel

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INTRODUCTION
A common tendency in transportation pipeline development, particularly, for main gas and oil pipelines, is a gradual increase in their service life and performance [1]. The problem is particularly acute since the pipelines today are subjected to unfavorable weather conditions, e.g., at low temperatures. A challenging task in this respect is to extend the service life of oil pipes by improving their mechanical properties [2]. Specifically, the fracture toughness—the major characteristics of crack resistance—has to be increased.

Main detrimental factors affecting the strength and crack resistance of pipe steels are attributed to tensile stresses and corrosion of the outer surface of pipes arising in underground conditions due to delamination or rupture of protective coating and localized corrosion of the inner surface [3].

Currently available approaches to characterizing the base metal ductility allow estimating the dynamic crack initiation toughness, which is crucial for the prediction of gas and oil pipelines failure [4]. It requires development of robust methods for the fracture energy determination in pipe steels with account of the shape of stress concentrators. These data can be used to account for the influence of embrittlement factors on the impact deformation resistance of pipe steels. Furthermore, modern low-carbon steels produced by thermomechanical processing of the initial sheet have different sensitivity to the concentrator shape and temperature/pressure loading parameters. It is therefore important to understand the fracture mechanisms operating at different stress stiffness values.

The present paper is aimed at obtaining a deeper insight into the influence of the notch shape on the impact fracture of 17MnSi steel at different temperatures with a focus on the low-temperature fracture behavior.

EXPERIMENTAL
A batch of specimens 10 × 10 × 55 mm with V-, U- and I-shaped notches of equal depth (2 mm) was machined. V- and U-notch specimens were made by standard milling cutters (ASTM E 23); I-notch specimens were made by electroerosion. Notch tip radius: U-1.0 mm; V-10.25 mm; I-0.1 mm before low-temperature impact testing. The specimens were kept in a cooling chamber Luda pr780 for 10 minutes in the temperature range from −60 °C to 0 °C. They were then rapidly mounted (did not exceed 5 seconds) into the grips of the impact pendulum Instron 4509MPK for testing. At least three specimens of each type were tested at temperatures 20, −20, and −40 °C.

INVESTIGATION RESULTS
Typically for structural steels, the test temperature dependence of impact toughness (Fig. 1a) exhibits several characteristics regions [5, 6]. In the lower shelf (from T = −60 °C to T = −40 °C) the specimen exhibits a fracture without pronounced signs of plastic deformation. The increase of the test temperature up to about 20 °C results in a combined brittle and ductile fracture mechanism. The upper shelf (from T = 0 °C to T = 0 °C) corresponds to the region of ductile fracture characterized by intensive plastic deformation on both micro- and macro-scales. It is commonly accepted [6, 7], that fracture in this region is induced by specific microscopic mechanisms [8].

It should be noted that the impact toughness of U-notched specimens is about 3 times higher in the entire test temperature range than that of V-notch specimens (Fig. 1c). It can be assumed approximately that the impact toughness value for specimens with all three types of notches linearly decreases with the decreasing test temperature.

The obtained dynamic loading curves of the specimens corroborate their sensitivity to changes in the macroscopic location of the crack initiation. The V-notch loading curve is typical of ductile fracture within the entire studied test temperature range from 20 °C to −60 °C [9] for all specimens tested including those with sharper V- and notches. The shape of the impact diagrams of the V- and notches specimen is almost the same, which indicates that crack initiation and growth occur similarly.

RESULTS
The impact toughness values of 17MnSi steel specimens with different notches under impact loading (i – initiation, p – propagation) are presented in Table 1.

Table 1. Impact toughness test results and fracture energy of 17MnSi steel specimens with different notches under impact loading (i – initiation, p – propagation)

<table>
<thead>
<tr>
<th>T/°C</th>
<th>V-notch</th>
<th>U-notch</th>
<th>I-notch</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>9.3±1.1</td>
<td>7.26±2.47</td>
<td>32.8±2.8</td>
</tr>
<tr>
<td>40</td>
<td>20±2.3</td>
<td>15.82±4.06</td>
<td>26.5±2.56</td>
</tr>
<tr>
<td>20</td>
<td>55±27.3</td>
<td>13.17±10.56</td>
<td>16±1.02</td>
</tr>
</tbody>
</table>

CONCLUSION
An approach towards fracture characterization has been suggested based on the description of plastic deformation of impact fracture specimens on the stage of crack initiation and propagation at ambient and low temperatures. The analysis of the shape of impact loading diagrams and energy fracture values for impact loaded specimens of pipe 17MnSi steel revealed the fracture mechanisms of this steel on the notch shape.

It was found that the test temperature reduction plays the decisive role in plastic strain localization and subsequent fracture impact of specimens with different notches. This is reflected in localization of deformation processes and decrease in crack propagation energy.

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REFERENCES

Fig. 1. Temperature dependence of impact toughness (a); impact diagrams in the load/displacement coordinates at test temperatures: 20 °C (b); −20 °C (c); −60 °C (d); for V-, U- and I-notch specimens.

Fig. 2. Temperature dependence of the CF parameter of 17MnSi steel specimens with V- (a), U- (b), I-notch (c).

Fig. 3. Schematic diagram illustrating the scheme of the sampling for the T/C test.