Role of hydrogen in service degradation of the physical and mechanical properties of structural steels

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Scope of Lecture

1. Introduction
2. The regularities and effect of hydrogen on degradation of properties
3. Dissipated damaging as the peculiarity of in-service degradation
4. In-laboratory modeling of in-service degradation
5. Evaluation of in-service degradation by monitoring of electrochemical properties
6. New challenges in material degradation
7. Conclusion
Degradation of nuclear and heat power station, oil refinery steels

Degradation of portal cranes
Failure of transit gas pipeline

2. The regularities and effect of hydrogen on degradation of properties
Oil pipeline

Gas pipeline

Oil storage tank steel

The low carbon (0.2 C) steel, 30 years of service

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact strength, $[J/cm^2]$</td>
<td>I</td>
</tr>
<tr>
<td>$K \times 10^{-2}, g/m \cdot hour$</td>
<td>72</td>
</tr>
</tbody>
</table>
$0.10C-1.6Mn-0.30Si$ steel, 28 years of service

KCV tests of transit oil pipeline steel

<table>
<thead>
<tr>
<th>State</th>
<th>KCV, J/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>virgin</td>
<td>180</td>
</tr>
<tr>
<td>“top”</td>
<td>95</td>
</tr>
<tr>
<td>“bottom”</td>
<td>??</td>
</tr>
</tbody>
</table>
### The peculiarities of in-service degradation of trunk gas pipeline steels

<table>
<thead>
<tr>
<th>Steel</th>
<th>Service, years</th>
<th>Part of pipe</th>
<th>$\sigma_{ys}$, MPa</th>
<th>$\sigma_{UTS}$, MPa</th>
<th>RA, %</th>
<th>Elong, %</th>
<th>Hardening, $J/J_{0.2}$, kN/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>X52</td>
<td>–</td>
<td></td>
<td>355</td>
<td>475</td>
<td>72.9</td>
<td>22.7</td>
<td>0.59</td>
</tr>
<tr>
<td>X52-12</td>
<td>30</td>
<td>Down</td>
<td>268</td>
<td>451</td>
<td>64.4</td>
<td>20.8</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Top</td>
<td>255</td>
<td>460</td>
<td>62.5</td>
<td>22.9</td>
<td>0.74</td>
</tr>
<tr>
<td>X52-10</td>
<td></td>
<td>Down</td>
<td>362</td>
<td>536</td>
<td>54.6</td>
<td>29.7</td>
<td>0.82</td>
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<td></td>
<td></td>
<td>Top</td>
<td>335</td>
<td>538</td>
<td>55.0</td>
<td>28.8</td>
<td>0.82</td>
</tr>
<tr>
<td>17G1S</td>
<td>–</td>
<td></td>
<td>378</td>
<td>595</td>
<td>79.0</td>
<td>20.2</td>
<td>0.58</td>
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<tr>
<td></td>
<td>28</td>
<td></td>
<td>403</td>
<td>590</td>
<td>68.2</td>
<td>20.5</td>
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<td>29</td>
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<td>345</td>
<td>547</td>
<td>71.1</td>
<td>19.6</td>
<td>0.76</td>
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<td>31</td>
<td></td>
<td>419</td>
<td>574</td>
<td>73.8</td>
<td>21.8</td>
<td>0.76  87/201</td>
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<tr>
<td></td>
<td>38</td>
<td></td>
<td>357</td>
<td>520</td>
<td>73.1</td>
<td>25.4</td>
<td>0.97</td>
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<tr>
<td></td>
<td>40</td>
<td></td>
<td>302</td>
<td>515</td>
<td>69.2</td>
<td>26.3</td>
<td>0.75</td>
</tr>
</tbody>
</table>

### Low carbon gas pipeline steels after 28-40 years of service

![Graph showing hardness (HB) vs. service time (years) for steel X52 and 17G1S.](image)
17G1S low carbon gas pipeline steel after 28-40 years of service

Charpy testing of X52 steel

Total fracture energy (1) and its components of crack initiation (2) and crack propagation (3)
Comparison of sensitivity to degradation the characteristics of brittle fracture resistance for some pipeline steels 14KhGS, 17GS, 17G1S, X52, X60

3. Dissipated damaging as the peculiarity of in-service degradation
Two principal stages of in-bulk material degradation

Deformation aging

30 years of service – critical age
from the point of considering
in-bulk material damages!

3.1. Reduction of strength and brittle fracture resistance is a special phenomenon of in-service degradation, caused by accumulation of defects.

3.2. This phenomenon is accompanied by an elongation increase and reduction of area with metal service.

The phenomena of degradation caused by dissipated damaging
3.3. Damaging become apparent in a decrease of (pseudo ?) elastic module (preliminary damaging) and a decrease of (pseudo ?) yield strength (creation of defects during loading in elastic region)

Compliance is higher
Elastic modulus is constant

Compliance is higher
Is elastic modulus constant?
3.4. Thicker “lips of stretching” on fracture surface after fracture toughness tests are expected for virgin material.

Deformation at the crack tip (dotted line) of specimens of different thickness in as-received state (a, b) and after service (c).

4. In-laboratory modeling of in-service degradation.
Generelized data about in-service degradation of some mechanical properties

![Graphs showing data about in-service degradation](image)

Usually artificial (in-laboratory) degradation consists in a preliminary plastic deformation (10 \%) with the following heating to 250 °C and holding 1 hour (Soviet standard GOST 7268-82). It models a deformation aging, when strength, hardness are increased and brittle fracture resistance is decreased.

We developed the method which takes into consideration an effect of hydrogen on the degradation process and models a process of dissipated damaging:

- Preliminary (electrolytic charging) hydrogenation of specimen;
- Electrolytic coating of specimen by copper for hydrogen desorption prevention;
- Long-term holding (up to 30 days) of specimen under static loading closer to service one;
- Holding of specimen at 250 °C for hydrogen desorption and deformation aging.
Reduction of area

Literature data

New developed method

Standard GOST 7268-82

Elongation

Literature data

New developed method

Standard GOST 7268-82
**Literature data**

Standard GOST 7268-82

**σ\text{ys}/σ\text{uts} ratio**

**New developed method**

Impact strength and fracture toughness

Literature data

New developed method

Standard GOST 7268-82
5. Evaluation of in-service degradation by monitoring of electrochemical properties

Correlation between degradation the mechanical (impact strength $KCV$) and electrochemical (polarization resistance $Rp$) characteristics

$$\frac{R_p^{\text{expl}}}{R_p^{\text{virgin}}} = 0.91 \frac{KCV^{\text{expl}}}{KCV^{\text{virgin}}} + 0.09$$

$R = 0.976$
Working environment should not be obligatory used as environment for monitoring of electrochemical characteristics!

6. New challenges in material degradation

The topic for the future Summer School ???
Old Wroclaw bridges

G. LESIUK, M. SZATA, 13th Conference on Fracture Mechanics
September 05 – 07, 2011, Opole, Poland
Materials Science (Springer), 2012

(1861r.) (1875r.) (1876r.)

(1885r.) (1888r.-1889r.) (1895r.-1897r.)

Old “Shukhov’s towers”

Сравнение высот Эйфелевой башни (1889г.) и Шуховских радиомачты (1919г.) по первоначальному проекту
Degradation of concrete and reinforced concrete

Damaged bridges
Tashlyk hydro accumulative station
The scheme of injection technology

The problem involves material science, corrosion and mechanical (fracture mechanics) aspects

7. Conclusion
Thank you for your attention!

Dziękuję za uwagę!
Danke für Ihre Aufmerksamkeit!
Дякую за увагу!