9% Ni Steel with High Brittle Crack Arretability†

1. Introduction

With the rapid increases in energy demand in Asia, mounting problems with the global environment are likely to increase the use of clean energy. This trend has already increased the demand for liquefied natural gas (LNG), an energy with lower CO₂ emissions than coal and petroleum, and one which will be stably available for many years to come. Many LNG tanks are now in use in Japan and abroad. The safety of these tanks must be maintained at high levels at all times. The inner-tanks of ground type LNG tanks are composed of 9% Ni steel plates with excellent low-temperature toughness. In addition to robust suppression of the initiation of brittle cracks in the LNG temperature region (−162°C), a crucial in the material design for this steel is to maximize the brittle crack arrestability. High brittle crack arrestability is an indispensable defense against LNG tank breakdown accidents.

JFE Steel has developed a 9% Ni steel capable of suppressing the initiation of brittle cracks more robustly than conventional steels. The new steel is manufactured by a direct quenching and tempering (DQ-T) process and a new JFE technology for stably manufacture by a Super-OLAC® (On-Line Accelerated Cooling) process with excellent temperature controllability. In this report we compare the general performance and brittle crack arrestability of the base metal of the direct-quenched and tempered (DQ-T) 9% Ni steel and a quenched and tempered (Q-T) steel.

2. Features of Direct-Quenched and Tempered 9% Ni Steel

2.1 Tested Steel

The chemical composition of the tested DQ-T steel is shown in Table 1. The P and S contents are controlled to sufficiently low levels and meet the SL9N590 specification of JIS G 3127 (JIS: Japanese Industrial Standards). After reducing the plate thickness to 32 mm by rolling under appropriate conditions, direct quenching (DQ) is carried out from a temperature of not less than the Ar₃ point, and the steel is tempered at 580°C. Super-OLAC is applied to the DQ process. The Q-T steel examined for comparison is produced at a quenching temperature of 810°C and tempering temperature of 565°C.

2.2 Microstructures

The microstructures of the tested DQ-T and Q-T steels are shown in Photo 1. Both steels have a tempered martensite structure. The Q-T steel has equiaxed grains, whereas the Q-T steel exhibits refinement of microstructures such as packets and blocks, and elongated grains due to the rolling before the DQ.

2.3 Mechanical Properties

The mechanical properties of the tested steels are shown in Table 2. Strength and toughness sufficient to meet the JIS G3127 SL9N590 specifications are obtained in the DQ-T steel. The strength in the plate thickness direction differs little between the DQ-T and Q-T steels, and both steels have uniform hardness distributions in the plate thickness direction (Fig. 1).

2.4 Brittle Crack Arrestability

The brittle crack arrestability was evaluated by conducting a surface-notched double tension test. The specimen shape is shown in Fig. 2. The specimen has a sharp 0.14 mm-wide sharp notch to serve as a simulated...
Surface defect running from a crack initiation portion to a propagation portion. The test was conducted at \(-170^\circ C\) and \(-196^\circ C\).

The results of the surface-notched double tension test are shown in Fig. 3. An example of a fractured surface after the test is shown in Photo 2. The applied stress in Fig. 3 indicates the value of a stress applied to a crack propagation portion, and the arrested crack length indicates the length from the inlet of a crack propagation portion to the leading end of a brittle crack. The upward arrow in Fig. 3 indicates which a crack leads to fracture without being arrested.

In the Q-T steel, a crack is arrested even when a stress of 490 MPa is applied at \(-170^\circ C\) (versus an allowable stress of 375 MPa). Yet when a stress of 294 MPa is applied at lower temperature of \(-196^\circ C\), a crack that has been initiated passes through the notched part and pierces through the specimen without being arrested.

In the DQ-T steel subjected to a stress of 539 MPa at \(-196^\circ C\), on the other hand, a crack that has propagated through the notched part is arrested immediately after passing through the leading end of the notch without reaching the steel plate surface (Photo 2).

From the foregoing it was ascertained that the 9% Ni steel manufactured by the DQ-T process has a drastically higher brittle crack arrestability than the Q-T steel.

### Table 2: Mechanical properties of 9%Ni steels

<table>
<thead>
<tr>
<th>Position</th>
<th>Direction</th>
<th>YS (MPa)</th>
<th>TS (MPa)</th>
<th>EL (%)</th>
<th>(E_{-196^\circ C}) (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DQ-T</td>
<td>1/4t</td>
<td>Longitudinal 689 732 29 190</td>
<td></td>
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<tr>
<td></td>
<td>Transverse 710 747 28 180</td>
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<tr>
<td></td>
<td>1/2t</td>
<td>Longitudinal 691 733 30 187</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transverse 713 750 28 191</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q-T</td>
<td>1/4t</td>
<td>Longitudinal 679 719 30 218</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transverse 681 719 29 192</td>
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<tr>
<td></td>
<td>1/2t</td>
<td>Longitudinal 676 721 30 211</td>
<td></td>
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<tr>
<td></td>
<td>Transverse 677 718 29 202</td>
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</tbody>
</table>

JIS G 3127  SL9NS90  
\[\geq 590\] \[600\text{-}830\] \[\geq 21\]
\[\geq 41\text{ (Ave.)}\] \[\geq 34\text{ (min.)}\]

\(^1\)JIS No. 4 specimens  \(^2\)JIS 2 mm-V notch specimens
YS: Yield strength  TS: Tensile strength  EL: Elongation
\(E_{-196^\circ C}\): Charpy absorbed Energy at \(-196^\circ C\)

3. Concluding Remark

When manufactured by the DQ-T process under appropriate conditions, 9% Ni steels have sufficient strength and toughness to meet the standards, and a drastically higher brittle crack arrestability than Q-T.
9%Ni Steel with High Brittle Crack Arrestability

These steels are thus confirmed to meet the safety requirements for LNG tanks. Direct-quenched and tempered 9%Ni steels are expected to be widely used in energy applications, including the construction of LNG tanks.

Reference