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9% Ni Steel with High Brittle Crack Arrestability†

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 CO_2 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[1]. 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[2–6] and a new JFE technology for stably manufacture by a *Super*-OLAC® (On-Line Accelerated Cooling)[7] 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 Ar_3 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.

Table 1 Chemical composition of 9% Ni steel

(mass%)

	C	Si	Mn	P	S	Ni
Ladle	0.06	0.25	0.61	0.002	0.001	9.22
JIS G 3127 SL9N590	≦0.12	≦0.30	≦0.90	≦0.025	≦0.025	8.50–9.50

2.2 Microstructures

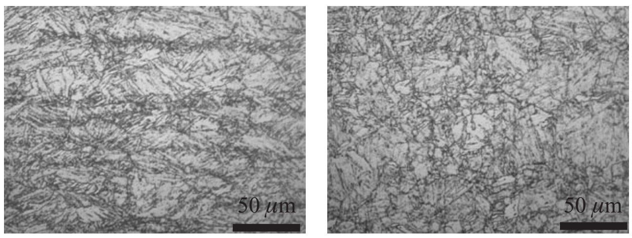
The microstructures of the tested DQ-T and Q-T steels are shown in **Photo 1**. Both steels have a tempered martensite structure. The Q-T steel has equiaxed grains, whereas the Q-T steel exhibits refinement of microstructures such as packets and blocks, and elongated grains due to the rolling before 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[2–4, 6]. The specimen shape is shown in **Fig. 2**. The specimen has a sharp 0.14 mm-wide sharp notch to serve as a simulated



(a) DQ-T (Direct quenching and tempering) (b) Q-T (Quenching and tempering)

Photo 1 Microstructures of 9% Ni steels

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Table 2 Mechanical properties of 9%Ni steels

	Position	Direction	Tensile test*1			Impact test*2
			YS (MPa)	TS (MPa)	EL (%)	$_{v}E_{-196°C}$ (J)
DQ-T	1/4t	Longitudinal	689	732	29	190
		Transverse	710	747	28	180
	1/2t	Longitudinal	691	733	30	187
		Transverse	713	750	28	191
Q-T	1/4t	Longitudinal	679	719	30	218
		Transverse	681	719	29	192
	1/2t	Longitudinal	676	721	30	211
		Transverse	677	718	29	202
JIS G 3127	SL9N590		≧590	690–830	≧21	≧41 (Ave.) ≧34 (min.)

*1JIS No. 4 specimens *2JIS 2 mm-V notch specimens
YS: Yield strength TS: Tensile strength EL: Elongation
$_{v}E_{-196°C}$: Charpy absorbed Energy at −196°C

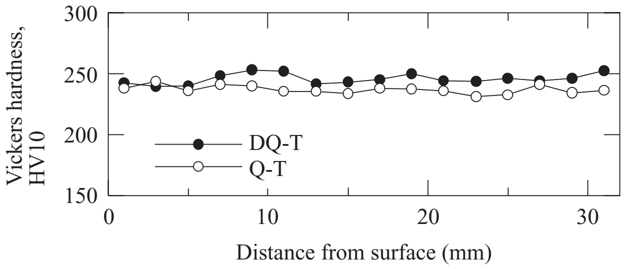


Fig. 1 Hardness distribution over the thickness of 9% Ni steels

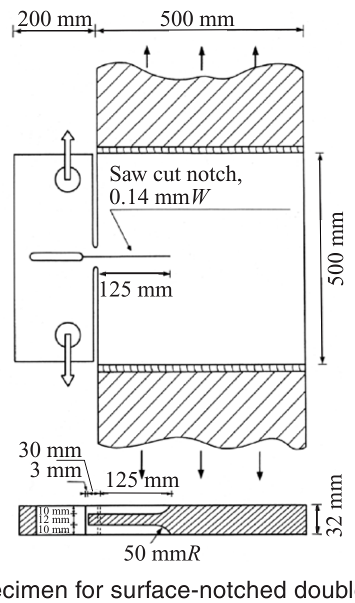


Fig. 2 Specimen for surface-notched double tension test

surface defect running from a crack initiation portion to a propagation portion. The test was conducted at −170°C and −196°C.

The results of the surface-notched double tension test are shown in **Fig. 3**. An example of a fractured surface

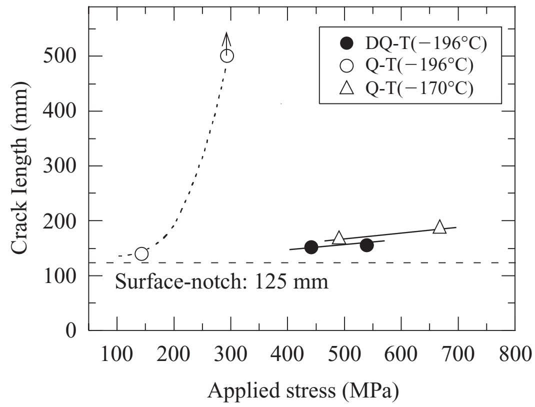
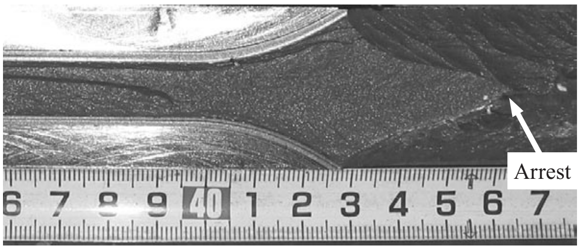


Fig. 3 Results of surface-notched double tension test



DQ-T Testing temperature: −196°C Applied stress: 539 MPa

Photo 2 Fracture appearance of surface-notched double tension test

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°C (versus an allowable stress of 375 MPa). Yet when a stress of 294 MPa is applied at lower temperature of −196°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°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.

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 steels. 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

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