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530N/mm^2 Tensile Strength Grade Steel Plate for Multi-Purpose Gas Carrier

Masaaki NAGAHARA*[1] Hidenori FUKAMI*[2]

Abstract

The TS530N/mm^2 grade steel plate applicable to the tank for mult-purpose gas carriers was developed. This developed steel plate has the toughness excellent in base metal and HAZ according to improvement technology in HAZ toughness, such as HTUFF® and Ti oxide technology, and CLC process, though it is strength higher than TS490N/mm^2 grade steel plate.

1. Introduction

Multi-purpose gas carriers, or combination tankers, that carry liquefied ammonia as well as LPG are increasing in number lately, thus the steel for low temperature service used for the tanks of this type of vessels are required to have resistance to the stress corrosion cracking (hereinafter referred to as SCC) which is caused by ammonia, in addition to the properties required for steels for common LPG tanks. According to the IGC code [1)], which is an international code for the structure and equipment of liquefied gas carriers, the yield point (YP) or yield strength (YS) of base metal of steel for low temperature service used for ammonia tanks must be 440N/mm^2 or less from the viewpoint of SCC resistance.

On the other hand, as the size of carrier tanks becomes larger and their internal pressure higher in order to improve the transportation efficiency of liquefied gas, the steel for low temperature service for such applications are required to have a higher strength than that of conventional TS490N/mm^2-grade steels.

In response to these requirements, Nippon Steel Corporation has developed a new TS530N/mm^2-grade steel for low temperature service excellent in weldability and resistance to the ammonia-induced SCC. The steel was developed on the basis of the Continuous on-Line Control Process (CLC) and the technologies for enhancing Heat Affected Zone (HAZ) toughness such as the Super High HAZ Toughness Technology with Fine Microstructure Imparted by Fine Particles (hereinafter referred to as the HTUFF®) and Ti oxide technology. **Table 1** shows an example of the performance figures required for steel for low temperature service for the tanks of LPG carriers that carry also liquefied ammonia; here the YS of the steel is equal to or higher than 355N/mm^2, and the design operating temperature of the tanks is –48°C. According to the design guideline of the IGC code, the design stress of steel material must be 1/3 of the lower limit of its tensile strength (TS) or 1/2 of the lower limit of YS, whichever the smaller. In the development study of the new plate product, its target TS was provisionally set at 530N/mm^2 in view of the above.

Table 1 Example of a demand performance

Tensile test		Charpy impact test		
YS (N/mm^2)	TS (N/mm^2)	Thickness t (mm)	Test temp. (°C)	Energy (J)
355/440	533/610	t ≤25	– 53	Transvers Ave. ≥27 Min. ≥19
		25< t ≤30	– 58	
		30< t ≤35	– 63	
		35< t ≤40	– 68	

The present paper describes the material properties of the developed TS530N/mm^2-class steel for low temperature service.

2. Properties of TS530N/mm^2-Grade Steel for Low Temperature Service

2.1 Chemical composition and production method

Table 2 shows an example of the chemical composition of the developed steel. The properties of the developed steel are described below. For the purpose of realizing a good and stable toughness of welded joints at a test temperature of –68°C, the technologies to re-

*[1] Oita Works

*[2] Nippon Steel Corporation, European Office

Table 2 Example of the chemical compositions of development steel plates

(mass %)

Steel	C	Si	Mn	P	S	Others	Ceq	Treatment
A	0.08	0.23	1.42	0.006	0.002	Cu, Ni, Nb, Ti, Ca	0.34	HTUFF
B	0.08	0.18	1.53	0.005	0.003	Cu, Ni, Nb, Ti	0.38	Ti-O

Ceq = C+Mn/6+(Cu+Ni)/15+(Cr+Mo+V)/5

fine the effective crystal grain size of HAZ such as the HTUFF and the Ti oxide technology are employed in the developed steel. In addition, the contents of C, Si, Mn, Cu and Ni are controlled to realize a base metal strength of TS530N/mm^2 or more through the CLC process and at the same time, to suppress the formation of martensite-austenite constituents, which act as initial points of fracture in HAZ. The conditions of the reheating, rolling and cooling of the developed steel plate are strictly controlled in the CLC process in order that the TS of base metal may be 530N/mm^2 or more, the YS of base metal fall within a range of 355 to 440N/mm^2, and a good and stable toughness be obtained in base metal at a test temperature of –68 to –53°C.

2.2 Mechanical properties of base metal

Table 3 shows some of the results of tensile and Charpy impact tests of the base metal of the developed steel plate 40 mm in thickness. It is clear in the table that the developed steel plate has sufficiently high TS, and YS within the required range. The average absorbed energy at a test temperature of –68°C exceeds 200 J, evidencing good toughness of the developed product.

2.3 Properties of welded joints

(1) Charpy impact test results of welded joints

Specimens of the developed steel plate 40 mm in thickness were welded by submerged arc welding (SAW) under different conditions such as those shown in **Table 4**, and the toughness of the welded joints was evaluated through Charpy impact tests. **Fig. 1** shows some of the results. Here, notches of different test pieces were cut at different positions of HAZ. The average absorbed energy of all the test pieces at –68°C, including those having a notch at a fusion line (FL), was over 100 J, evidencing good HAZ toughness of the new steel plate.

(2) Evaluation results of fracture toughness

For the purpose of evaluating the fracture toughness of the welded joints, center deep notch tests were carried out using test pieces each having a notch 0.1 mm in width machined at the center position corresponding to a fusion line. **Fig. 2** shows some of the results. The K_C value at –48°C, the design temperature, was 6,000N $\sqrt{\mathrm{mm}}$ /mm^2 or more.

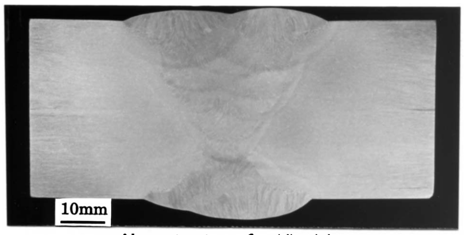
The fracture toughness was evaluated through CTOD tests as well, where each of the test pieces had a notch also at a position corresponding to a fusion line. **Fig. 3** shows some of the results. The fracture toughness of joints welded by shielded metal-arc welding (SMAW) was also evaluated through these tests. In the joints welded by either of the methods, the critical CTOD value at –48°C, the

Table 3 Example of the mechanical properties of development steel plates

Steel	Thickness (mm)	Tensile test		Charpy impact test
		YS (N/mm^2)	TS (N/mm^2)	$_{V}E_{-68°C}$ Ave./min. (J)
A	40	386	577	258/168
B	40	374	583	226/222

Table 4 Example of welding condition

Welding method	Thickness (mm)	Welding material	Welding conditions
SAW (double V groove)	40	Wire : Y-3Ni (4.8 mm) Flux : NB55LS	Current : 750A Voltage : 32V Speed : 30cm/min Heat input(H.I.): 48kJ/cm



Macrostructure of welding joint

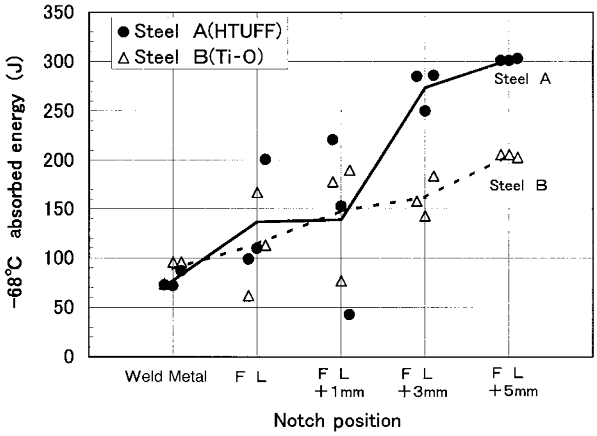


Fig. 1 Charpy impact test results of SAW welded joints

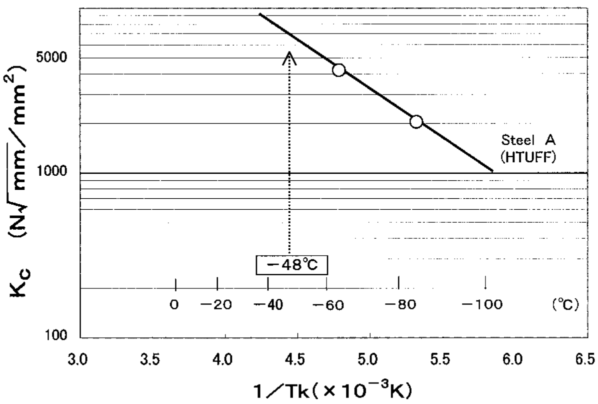


Fig. 2 Center deep notch test results of SAW welded joints

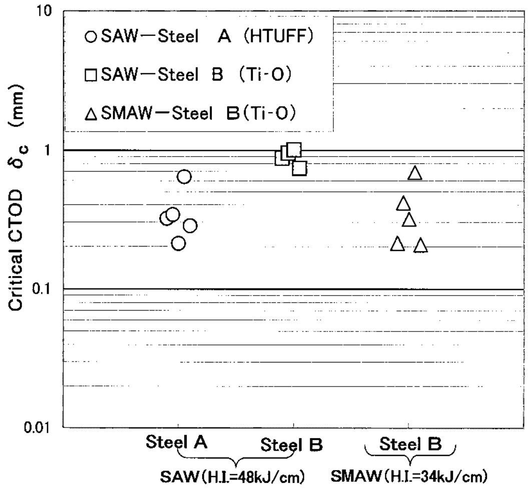


Fig. 3 CTOD test results of welded joints

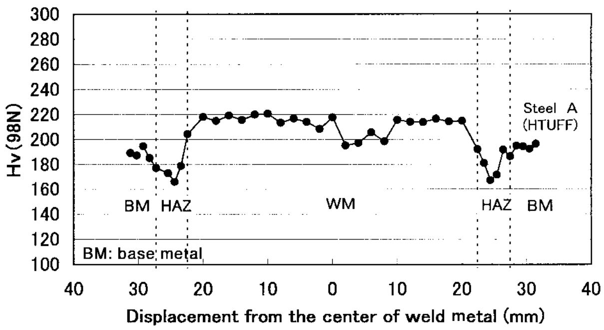


Fig. 4 Hardness distribution of SAW welded joints

design temperature, was 0.2 mm or more, higher than 0.1 mm, which is considered the lower limit of the critical CTOD value range for securing the safety of a welded structure.

(3) Results of hardness distribution measurement of welded joints

Fig. 4 shows an example of the hardness distribution measurement results of welded joints of the developed steel plates. The Hv(98N) of HAZ and base metal is 200 or less, lower than Hv(98N) 210, which is the indicator proposed by Masumoto as the upper limit of the hardness range for inhibiting SCC [2].

3. Closing

The TS530N/mm^2-grade steel for low temperature service for application to the tanks of multi-purpose gas carriers for LPG and liquefied ammonia has been developed. The developed steel is for plates having a strength higher than that of a conventional TS490N/mm^2-grade low-temperature steel and despite the high strength, have an excellent low-temperature toughness and a YS controlled to 440N/mm^2 or less, thanks to the effects of HAZ toughness enhancement technologies such as the HTUFF and the Ti oxide technology and the CLC process.

The steel plate product has been actually applied to Bi-lobe type LPG tanks [3].

References

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