NIPPON STEEL TECHNICAL REPORT No. 90 JULY 2004

UDC 699 . 14 . 018 . 292 / 293

390 MPa Yield Strength Steel Plate for Large Heat-input Welding for Large Container Ships

Masanori MINAGAWA*[1] Koji ISHIDA*[2]
Yuji FUNATSU*[2] Shiro IMAI*[3]

Abstract

Large container ships require steel plates with large thicknesses, and high strength and high HAZ toughness. In order to satisfy these requirements, a YP390 MPa grade steel plate for large heat-input welding was developed by the authors. HTUFF® technology was utilized in this steel which prevents austenite grain coarsening at high temperature with fine oxide particles. This plate can be used for 1 pass electro-gas-arc-welding.

1. Introduction

Container ships that have been under design over the past several years have continued to grow in size[1,2)], requiring thicknesses of up to 50 mm in their structures and high strengths that exceed yield strengths of 355 MPa. Furthermore, the container ships of recent years use steel plates that have high toughness at heat affected zone (HAZ) enabling large heat-input welding.

The increase in foreign trade that has accompanied the dramatic economic and manufacturing expansions enjoyed in Southeast Asia can be offered as a background for the expanding sizes of container ships. Notably, there has been an impressive increase in marine exports (container freight) between East Asia, including both Korea and China, and Japan, Europe and the United States. Additionally, the larger sizes of recent container ships that approach the scale limit is a result of their attempts to maintain dominance in the heavily competitive international shipping markets. Container ships are also growing in size through the rationalizations brought about by global alliances, themselves also being an effort to maintain a competitive edge. Until the 1980's, the size of container ships was limited by the largest size of ship that could pass through the Panama Canal. However, as we entered the 1990's, we witnessed a dramatic rush to larger sizes of ships because of the development of shipping lanes that did not navigate through the Panama Canal.

Thick, high strength steel is used in container ships. However, there are two demerits in view of the structure requiring the upper deck to open to allow the loading and unloading of cargo, and in view of lightening the weight of the ships to allow for increased shipping efficiency (sailing speed). It is necessary to increase the structural strength and to reduce increased mass that accompanies the enlarged sizes of container ships, and so further thicknesses and higher strength have become demanded of steel plates.

Furthermore, because of the needs to shorten construction periods and to reduce costs, there have been advancements made in assembly efficiency. For example, in recent years there has been a trend toward the employment of a so-called electro-gas arc welding method that employs large heat-input welding of joints in one pass in the welding process. At the same time, there have been demands for increased toughness against the affects of welding heat that supports large heat-input welding. However, because welding input heat increases even more as the steel plates thicken, it is necessary to ensure characteristics under ever more stringent heat conditions.

Thus, with this as a background, this document reports on the development of a thick, high strength steel plate that has good quality welding coupling toughness for 1 pass electro-gas arc welding method.

2. Development Targets

Table 1 shows details on development targets. The base metal had yield strengths levels of YP390 MPa class; toughness level E grade; and was a steel plate having a thickness of 65 mm. The various characteristics were in line with shipping class regulations. With regard to the weld coupling characteristics, 1 pass welding (input heat volume approximately 40 kJ/mm) that is used in the hatch coaming and sheer strake processes which are important structural portions of the ship was used as the welding applied. Abiding to the

*[1] Oita R&D Lab.
*[2] Oita Works
*[3] Plate Sales Division

Table 1 Target properties

Base metal properties					Welded joints properties		
Thickness (mm)	YP (MPa)	TS (MPa)	El (%)	$_{V}E_{-40}$ (J)	Welding method	TS (MPa)	$_{V}E_{-20}$ (J)
65	≥ 390	510-650	≥ 20	≥ 41(ave.) ≥ 29(min.)	1pass VEGA	≥ 510	≥ 41(ave.) ≥ 29(min.)

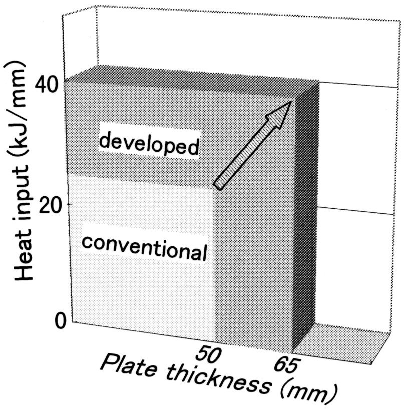

Fig. 1 Development goal

standards for E grade steel, Charpy absorbed energy at –20°C was a minimum of an average value of 41J, and each value was a minimal of 29J. The development targets described above greatly expanded on conventional steel from Nippon Steel with regard to fit this ranges and supported welding input heat range (see **Fig. 1**).

3. Concept of Development

Fig. 2 shows the general concept for steel development. It is not easy for steel plates to comprise all three features of thickness, high strength and high HAZ toughness. Conventionally, thermo-mechanical control process technology (or TMCP) was developed as means for satisfying superior welding characteristics as well as achieving high strengths. Varieties of highly performance steel plates beginning with those for ship construction, have been realized with that technology. However, by mainly utilizing transformation strengthening for TMCP, this resulted in reduced strengthening along with the thickening of the steel plates. Therefore, in order to enable higher strengths for thicker steel plates, strengthening elements must be added at the minimum. However, there are many cases in which adding elements that contribute to strengthened precipitation and solid solution were the causes of decreased HAZ toughness. For example, excessive additions of components such as carbon, silicon and niobium, caused reduced HAZ toughness by creating cementite, martensite-austenite constituent and hardened matrixes.

Focusing on high HAZ toughness, brittle structures, in which brittle cracks initiate, and coarse fractural units are micro-structural causes of decreased toughness. As a specific example, when coarse ferrite, coarse cementite which is adjacent to bainite, martensite-austenite constituent exist, brittle fractures occur easily. Therefore, in addition to the efforts to attain high strengths, efforts must also be made to refine grains and to restrict the creation of cementite, and martensite-austenite constituent (MA). As a technology for not hindering the most effective high strength, and for improving HAZ toughness, it was effective to refine the HAZ structure. Conventionally, titanium-nitride dispersion was effective to prevent austenite grains coarsening as an effort to improve HAZ toughness[3)].

However, at high temperatures near the melting point, titanium-nitride decomposed into a solid solution thereby reducing the effect of suppressing the coarsening of austenite grains. This is particularly true in that heat input amounts are notably high when performing one pass welding on thick steel plates which is the focus of this research. Exposure of a wide range of HAZ to high temperatures for long periods of time showed this trend with even greater notability. Thus, as a result, "HTUFF (Super High HAZ Toughness Technology with Fine Microstructure Imparted by Fine Particles)"[4)] was developed which used stable oxides even at high temperatures. In the development of this new steel plate, HTUFF was employed as the fundamental technology to realize fine microstructures for HAZ. Also, TMCP was employed to suppress brittleness in the structures, as well as including adjustments of the components through optimization of niobium and titanium in consideration of strength, and reduced solid solution nitrogen.

4. Features of the Developed Steel Plate

4.1 Base material characteristics

Table 2 shows details on the chemical compositions of the developed steel plates. 0.12% carbon was used as a base with minute amounts of niobium and titanium added as a strengthening element. In manufacturing, TMCP was used to satisfy high strength requirements with low carbon equivalent (Ceq.). **Table 3** shows details on the mechanical properties of the developed steel plates. The me-

Table 2 Chemical compositions

C	Si	Mn	P	S	Others	Ceq
0.12	0.28	1.40	0.009	0.003	Nb,Ti	0.36

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

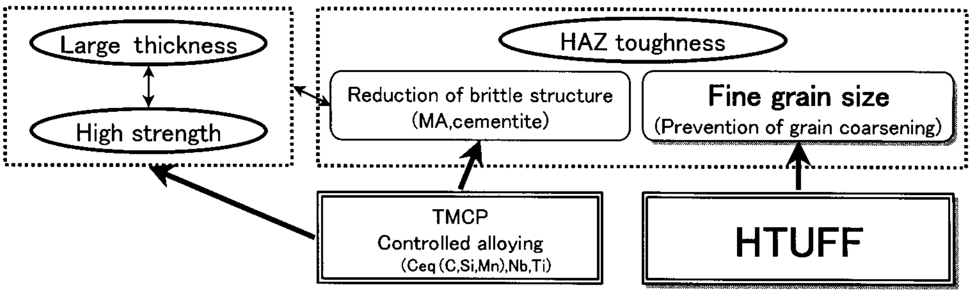

Fig. 2 Development concept of YP390 MPa steel plate for large heat-input welding

Table 3 Mechanical properties

Strength class	Thickness (mm)	Tensile test			Charpy impact test
		YP (N/mm²)	TS (N/mm²)	El (%)	$_{V}E_{ave}$ at – 40°C (J)
YP390	65	433	563	28	300

chanical characteristics satisfy target strengths and elongation. Toughness is also acceptable.

4.2 Large input heat welding coupler characteristics

Two-electrode VEGA®(Vibratory Electro Gas Arc welding) welding method[5-7] applied for evaluation of the large input heat welding coupler characteristics of this steel material. This welding method is a high performance welding method that applies two welding torches in the plate thickness direction as shown in **Fig. 3** with the one pass automatic welding method developed by the Nippon Steel Welding Products & Engineering Co., Ltd., and uses a flux wire in a swinging copper plate electrode, and a solid wire in the back side electrode, and uses a dedicated back material.

Table 4 shows welding conditions. Two-electrode VEGA® welding with a heat input of 39 kJ/mm was performed on a 65 mm thick steel plate, and then evaluated for the toughness of its welded joints. See **Photo 1** for an example of the macro structure.

Table 5 shows the results of the joint tension tests. This base material rupture has plenty of strength.

The welding joint toughness evaluation was brief performed using the V notch Charpy test and the test temperature was –20°C. **Fig. 4** shows the energy absorbed at the notch positions. All positions of the evaluation satisfied the target toughness values.

Photo 2 shows the microstructure of the welded joints. The coarseness of the old austenite grains was suppressed also near the fused portions.

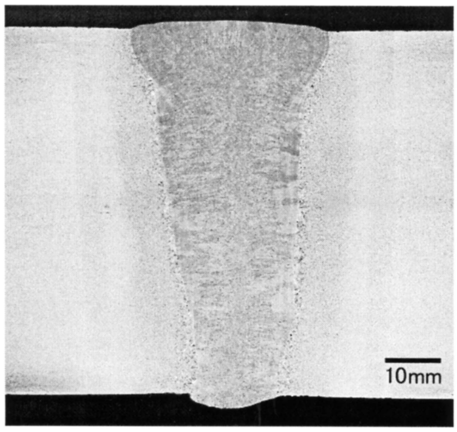

Photo 1 Macro structure of welded joint

Table 5 Tensile test of welded joint

Tensile strength (MPa)	Fracture position
588	Mother plate

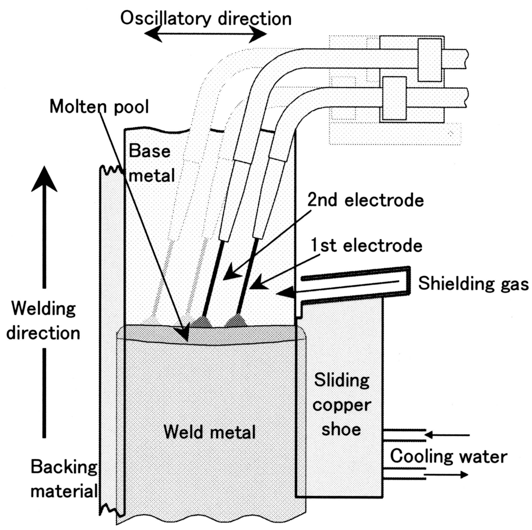

Fig. 3 Schematic of 2P-VEGA welding

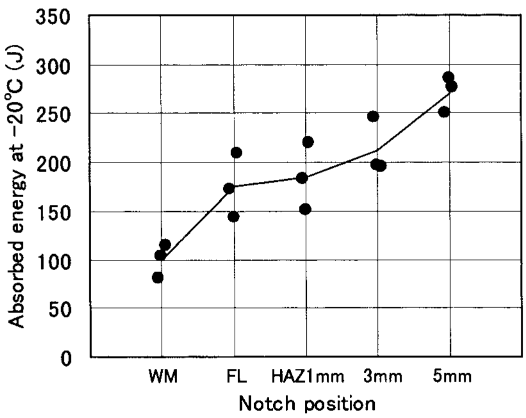

Fig. 4 Toughness of welded joint

Table 4 Conditions of VEGA welding

Thickness (mm)	Groove preparation		Electrodes		Welding current (A)	Arc voltage (V)	Welding speed (mm/min)	Heat input (kJ/cm)	Shielding gas	
	Groove angle	Root gap (mm)	No.	Wire type					Type	Flow rate (l/min)
65	20°	8	1st	Flux cored wire	410	41	50	39	CO_2	30-35
			2nd	Solid wire	400	40				

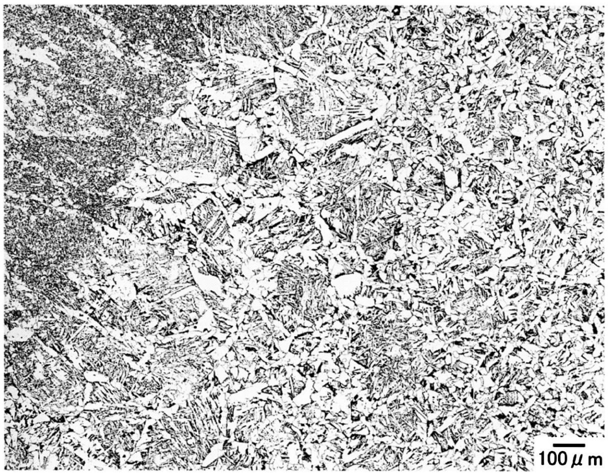

Photo 2 Micro structure of welded joint

5. Conclusions

A new highly strong and thick steel plate was developed that enables welding at high heat input temperatures thereby contributing to the larger sizes of container ships. This steel materials which is the fundamental technology of HTUFF that employs minute oxidized particles to realize fine microstructures for HAZ has good quality joint toughness even in the application of two electrode electro gas arc welding method (1 path electro-gas welding method) was developed as a high performance welding method. It is now available on the market.

References

1) Tanaka, Y. et al.:Mitsubisi Juko Giho. 34(5), 306(1997)
2) Nagatsuka, S. et al.:Kaiji Sangyo Kenkyusyo Ho. 360, 7(1996)
3) Kanazawa, S. et al.:Tetsu-to-Hagané. 61(11), 65(1975)
4) Kojima, A. et al.:Shinnittetsu-Giho. (380), 2(2004)
5) Kimoto, I. et al.:Welding Technology. 48(12), 98(2000)
6) Toyohara, C. et al.:Preprint of the National Meeting of J.W.S., 70, 2002, p.38
7) Ohkita, S. et al.:Preprint of the National Meeting of J.W.S., 70, 2002, p.40