Cost Effective Steel Plates for TLP Construction in the Gulf of Mexico

by

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Synopsis

This paper describes the latest development of steel plate which enables fast-track construction of offshore structures through short steel delivery periods and a short fabrication period with a minimized number of welding procedures and low preheat. The total cost saving effect by applying this steel was actually verified in the construction of Mars and Ram Powell Tension Leg Platforms (TLP) in the Gulf of Mexico. This was only possible because of newly developed mono-chemistry of API 2 W composition which ensures a high heat-affected zone (HAZ) CTOD toughness. In addition to this high steel performance, close teamwork between the end user, fabricator and steelmaker with uninhibited sharing of technical information was the other essential key for the success of these TLP construction projects.

1. Introduction

In the Gulf of Mexico, new construction of offshore structures is rapidly progressing based on expectation of a world-wide shortage of oil in the beginning of the 21 st century, resulting from a sharp increase in the demand for oil in China and India. Shell Offshore Inc. had a plan of consecutive TLP construction, at a pace of almost one TLP every other year until the year 2000.

In 1994, Shell began producing oil from Auger TLP which set a world record water depth of 2,860 feet in the Gulf of Mexico. Two other Shell TLP's called Mars and Ram-Powell which are now under construction will establish new records one after another in 1996 and 1998. The Ram-Powell field jointly owned by Shell Offshore, Amoco Production, and Exxon will be some 400 feet deeper than Shell's Auger platform. These huge platforms, which must withstand the winds and waves of deep waters without losing their moorings, have required improved technologies that include high performance 4" steel plates. Fast-track construction of the Mars and Ram-Powell platforms also required rapid qualification and production of the 50 ksi and 60 ksi steel plates.

Steel grades for TLP construction are classified as critical, special, primary, and secondary. Each classification has been designed from a fit-for-purpose perspective from the standpoint of toughness and quality control test frequency; but, good weldability with low preheat is required for all classifications. For the Mars and Ram-Powell TLP deck fabrication, API 2 W steels manufactured by a thermomechanical control process (TMCP) were selected from the point of view of their good weldability, with some modified stringent quality requirements. In addition, the use of TMCP (and TMR - thermomechanical rolling for some of the lighter gauges) allowed consolidation of the classification system into substantially fewer classifications without cost penalty and thus allowed designers to shorten and simplify the steel selection process, enabling quicker generation of critical material take off (MTO) drawings and accelerated start of steelmaking.

A base metal transverse Charpy V-notch transition temperature below -80°C was specified for every critical-use mother plate at the plate mid-width mid-thickness position. The transition approach, which was tied to results from the prequalification plates, was selected because it was proven during prequalification that achieving this ultralow 50% FATT (fracture appearance transition temperature) guarantees base-metal CTOD and drop-weight test (DWT) requirements. This procedure was adopted in lieu of performing base-metal CTOD and DWT testing on a production basis, in order to minimize the manufacturing lead time.

For the fast-track construction of the Mars and Ram-Powell TLP's, some positive considerations on steel specification and design were agreed other than the Charpy requirement. This required close cooperation and uninhibited sharing of knowledge between steelmaker and end user. From the steelmaker side, the solution was mono-chemistry steel design of very low carbon equivalent. Although a wide range of thicknesses and grades were supplied for the deck fabrication, every steel was separately manufactured with the same low carbon chemistry. This enabled a short steel delivery time through a simplified melting schedule, and a short fabrication period through the minimized number of welding procedures with low preheat. This was only possible because of precisely controlled innovative proprietary TMCP practice. In addition, high heat-affected zone (HAZ) CTOD toughness, free of local brittle zones, was also achieved by the specifically modified API 2 W composition.

In addition to the high performance of the steel, close teamwork between the end user, fabricator and steelmaker with un-inhibited sharing of technical information was the other essential key for the success of these TLP construction projects. This has been cultivated through cooperation in preparation for TLP construction. Frequent inter communication through electronic mail between the end user and steel maker on technical or delivery matters helped greatly in grasping each other's current concerns and in establishing mutual trust.

This paper describes the steel plates which can enhance cost effective construction of offshore structures, especially focusing on the critical steel plates for deck construction, also describing some business activities in supplying the steels for Mars and Ram-Powell TLP construction.

2. Supply Record of TLP Steel in the Gulf of Mexico

For Auger, Mars, and Ram-Powell TLP's, whose locations in the Gulf of Mexico are shown in **Fig. 1**, Sumitomo Metals supplied or is supplying a very large amount of steel plates and pipes. **Table 1** shows this supply record. Sumitomo's supply share is increasing year after year, or TLP after TLP.

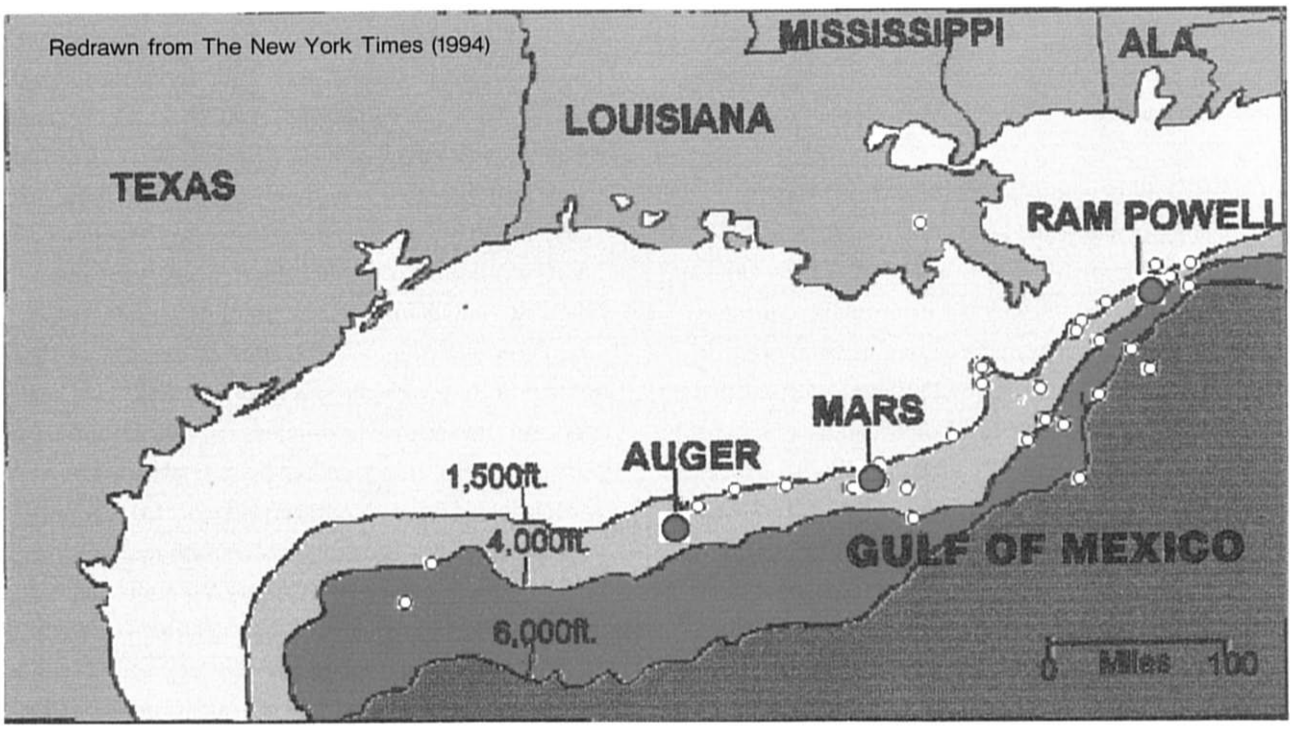


Fig. 1 Location of Shell TLP's in the Gulf of Mexico

Table 1 Sumitomo's steel supply record for the TLP's

TLP		Auger	Mars	Ram-Powell
Owner		Shell	Shell	Shell/Exxon /Amoco
Water depth		2 860 ft.	2 933 ft.	3 220 ft.
Production start		1994	1996	1998
Steel supply	Deck*	–	5 644 mt	6 387 mt
	Hull*	–	–	2 899 mt
	Tendon pipe	5 300 mt	5 520 mt	6 000 mt
	Pile*	–	2 899 mt	2 600 mt
	Seamless and others	12 900 mt	7 600 mt	3 600 mt

Note:* Steel plates were supplied.

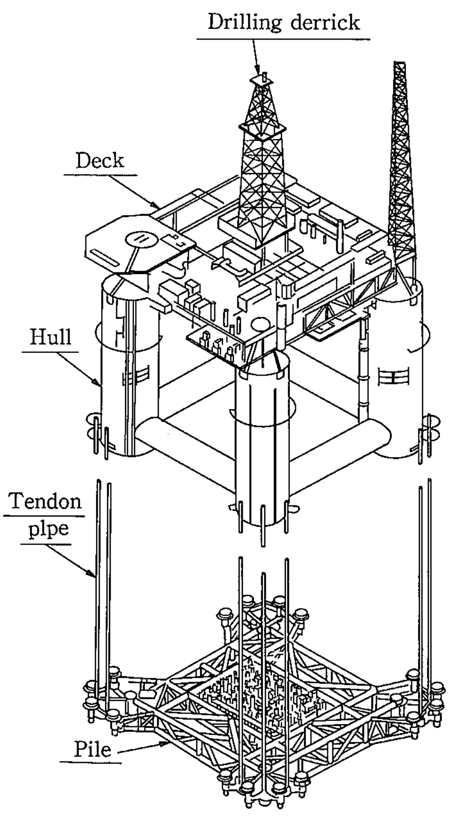


Fig. 2 General structure of TLP

3. Metallurgical Design for Critical Steel

For the critical steel, the API RP 2Z pre-production qualification requirement which deals with CTOD testing of the weld HAZ and hydrogen cold cracking testing, was applied with some modification by Shell Offshore Inc.[7] The chemical composition of the steel was specifically designed based on the mono-chemistry concept. The following three performances of the steel were given greater importance during the steel design:

(1) High HAZ CTOD toughness at -10°C at high, medium, and low heat input/interpass temperature combinations,

(2) High base-metal low temperature toughness (Charpy transition temperature of less than or equal to -80°C), and

(3) Good weldability to enable low preheat welding fabrication.

To achieve these performances the special chemical composition of low Pcm, ultralow Al, and precisely controlled low contents of Nb-Ti microalloying elements was designed based on recent knowledge of HAZ toughness improvement by low aluminum content [6),10)] and on the precipitation effect of Nb-Ti complex compounds[8),9)].

This chemistry design basis was specifically envisioned to suit the Mars and Ram-Powell TLP deck fabrication. In fact, the alloy basis and prequalification process was developed and begun between the steelmaker and the end user almost half a year before final project approval, thus cutting down on prequalification time that would normally be required after receipt of order. In addition to these chemical features, a distinctive TMCP was practiced to obtain the low temperature toughness of the base metal from thin to thick plates separately.

It requires quite advanced centerline segregation control and rolling and accelerated cooling practice for a heavy plate to achieve a Charpy fracture appearance transition temperature, vTrs, of less than -80°C at the mid-thickness position. The following metallurgical conceptual factors were deliberately controlled for the heavy deck plates:

(1) Very fine recrystallized austenite grain size at mid-thickness before controlled rolling,
(2) Introduction of sufficient cumulative strain (rolling reduction) at mid-thickness in the controlled rolling passes over a specific temperature range, and
(3) Delayed accelerated cooling after the completion of austenite recrystallization at mid-thickness.
(See BESSYO et al., 1991[3])

For the thinner plates, these TMCP parameters were also accurately set on grade-to-grade and thickness-to-thickness basis.

4. Qualification Testing

The critical steel for the deck required pre-qualification testing which was essentially in compliance with API RP 2 Z (1992)[1] but somewhat severer than the API RP 2 Z due to specific modifications by Shell Offshore Inc. The qualified heat input range was 0.7 kJ/mm, 3 kJ/mm, and 4.5 kJ/mm. Controlled interpass temperature of ambient (=<38°C) was coupled to the 0.7 kJ/mm heat input to generate maximum HAZ cooling rate conditions. Controlled interpass temperature of 250°C minimum was coupled to the 4.5 kJ/mm heat input to generate minimum HAZ cooling rate conditions. The HAZ CTOD test was performed at -10°C. The resistance to hydrogen cracking was examined with two diffusible hydrogen levels of standard (3-5 ml/100 g) and high (>10 ml/100 g).

The qualification test was conducted for 3" (76.2 mm) Gr. 60 and 4" (101.6 mm) Gr. 50 steel plates, having Pcm values of 0.18 % (carbon equivalent value of 0.39 %). **Table 2** summarizes the base metal test results. Every test specimen, including Charpy and Pellini drop-weight test (DWT) specimens, was extracted so that the centerline position of the specimen coincided with the plate mid-thickness, mid-width location. Both grade heavy plates satisfied their required high strength levels with low Pcm (or with low Ceq). The Charpy transition temperatures and the nil-ductility transition temperatures (NDTT's) of the DWTT were very low in the base metals and hardly deteriorated after 5 %-strain aging treatment at 250°C for 1 hour.

The HAZ toughness test was carried out in accordance with the API RP 2 Z by preparing three butt welds for both plates with a K-bevel joint preparation. **Table 3** shows the groove shapes and the other welding conditions. The heat inputs of three butt welds were set to 0.7 kJ/mm with GMAW, 3.0 kJ/mm and 4.5 kJ/mm with SAW. A 2 mm V-notch Charpy impact test and standard full-thickness CTOD test[4] were performed to examine the HAZ toughness at the vertical straight bevel side. **Figure 3** demonstrates the straightness of the coarse-grain HAZ's (CGHAZ's) by sectioning the CTOD specimens.

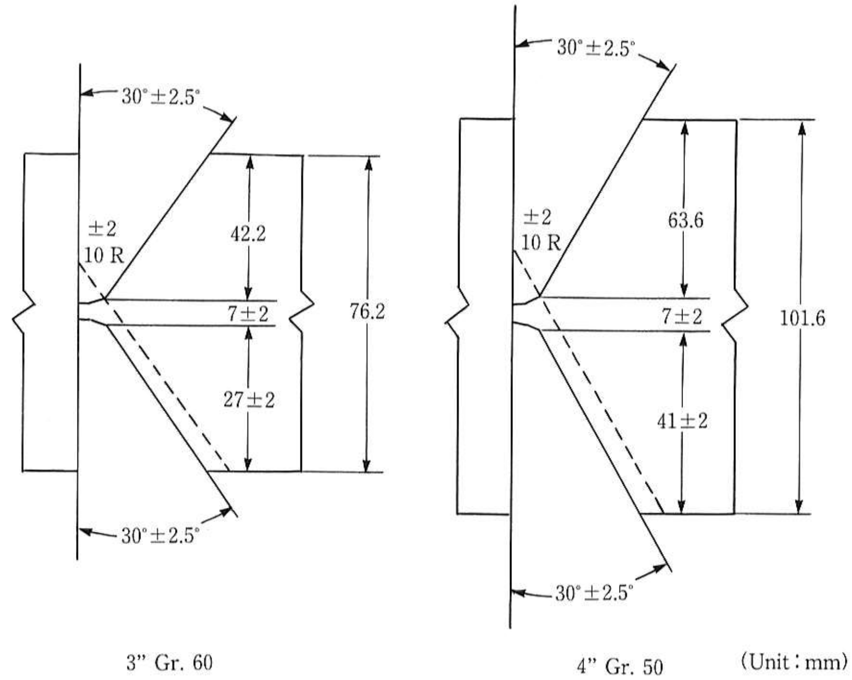
Figures 4 and **5** show the obtained Charpy impact and CTOD test results for the HAZ of 3" Gr. 60, which demonstrated that the test plate has remarkable low

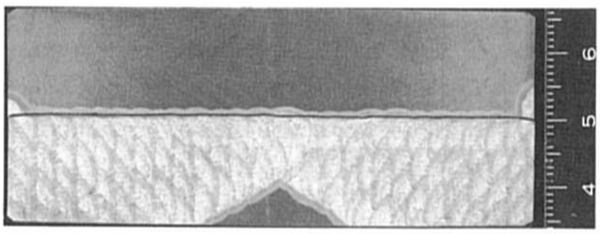
Table 2 Base metal test results

Test items		3" Gr. 60		4" Gr.50	
		Result	API 2 W	Result	API 2 W
Tensile test	Yield strength, N/mm²	441−458	414−586	381−413	345−483
	Tensile strength, N/mm²	537−551	Min. 517	496−530	Min. 448
	Elongation, %	30−35	Min. 22	27−34	Min. 23
Charpy test	vE-40°C, Joule	350−396	Min. 48	411−419	Min. 41
	vTrs,°C	−97	−	−89	−
Z-Tensile test	Reduction of area, %	65−72	(Min.30)	75−77	(Min.30)
DWTT	NDTT, °C	−90	−	−65	−
CTOD test	CTOD, mm	Min. 1.69	−	1.14	−
5% Aged test	Charpy vE-40°C, Joule	229−260	(Min. 48)	241−380	(Min. 41)
	NDTT,°C	−70	−	−60	−

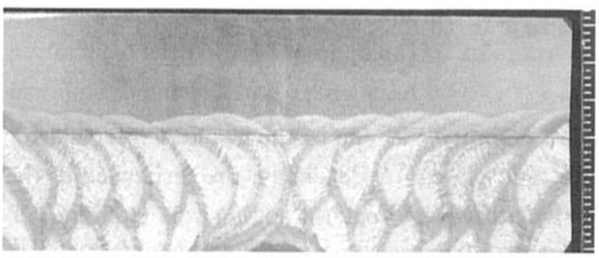
Note: ( ) indicates a supplementary requirement to API 2 W.

Table 3 Welding condition (Gr. 60-3", Gr. 50-4")

Heat input	Low	Middle	High
Welding method	GMAW	SAW	
Groove shape			
Heat input	0.7 kJ/mm	3.0kJ/mm	4.5kJ/mm
Welding material	Wire: # DW-55 L (AWS A 5.29 E 80 T 1-K 2) Shielding gas: CO_2 100%	Wire: # W-36 (AWS F 7 P 8-EH 14) Flux: BL-55 (AWS F 7 P 8-EH 14)	Wire: # W-36 (AWS F 7 P 8-EH 14) Flux: BL-55 (AWS F 7 P 8-EH 14)
Preheat temperature	Ambient	100°C	250°C min
Interpass temperature	Ambient	250°C max.	250°Cmin



(a) 0.7 kJ/mm



(b) 3.0 kJ/mm

Fig. 3 Typical macro-etched section of the HAZ CTOD specimens for 3" Gr. 60 steel, showing position of fatigue precrack tip

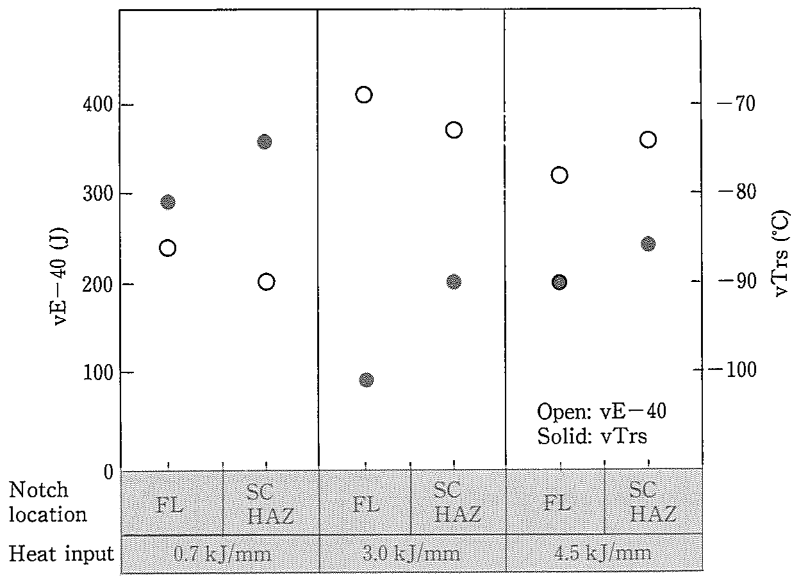


Fig. 4 HAZ Charpy test results for 3" Gr. 60

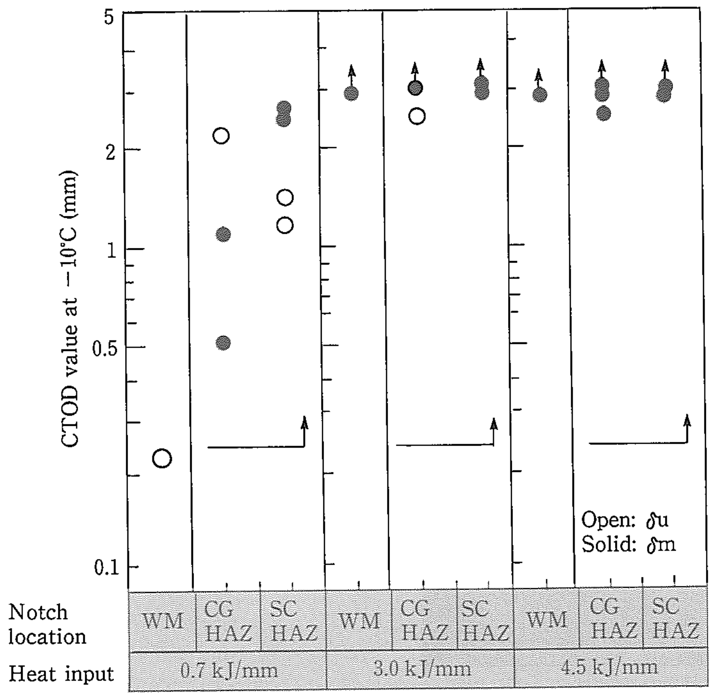


Fig. 5 HAZ CTOD test results for 3" Gr. 60

temperature toughness. In the Charpy test, both vE-40 and vTrs at the fusion lines were nearly the same as those at the subcritical HAZ (SCHAZ). This indicated successful microstructure control at the CGHAZ by the specially designed chemical composition of the steels. In the HAZ CTOD test, all the valid critical CTOD values at -10°C greatly exceeded the required 0.25 mm at the CGHAZ and SCHAZ positions.

Weldability was one of the greatest interests for the deck plates. Accordingly, the resistance of the test plates to hydrogen cracking was examined in some detail, beyond the required range by "Delayed Cracking Test" in the API RP 2 Z.

Figure 6 shows the bead-on-plate hardness results for 3" Gr. 60 steel at the heat input of 0.7 kJ/mm. The

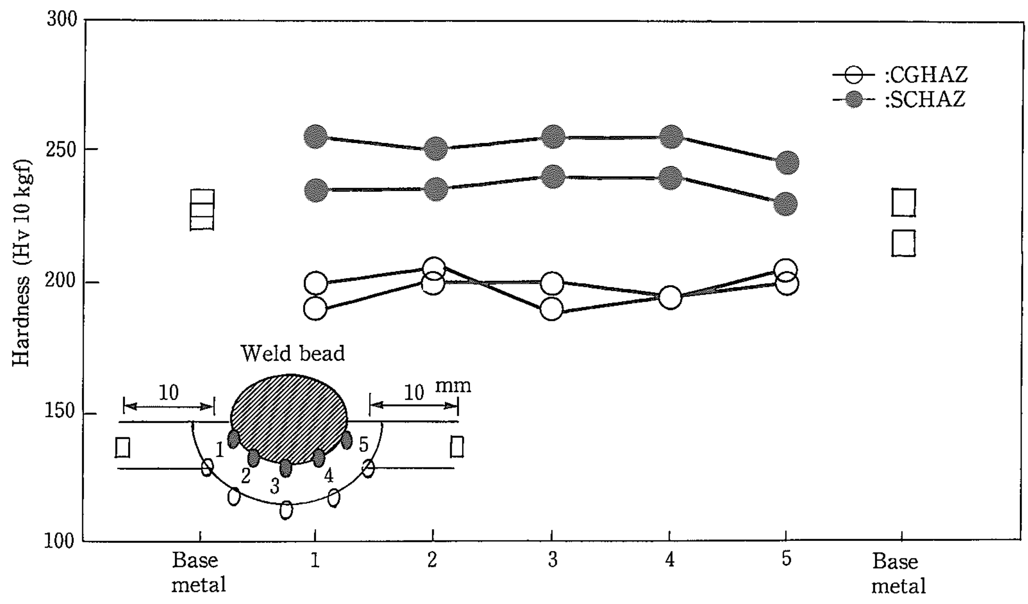


Fig. 6 Bead-on-plate hardness test results for 3" Gr. 60

hardness values in the CGHAZ were around 250 in the Vickers hardness test, well below the required 350 max.

Tekken type Y-groove cracking test was performed with two diffusible hydrogen levels: standard hydrogen level of 3.0 ml/100 g in accordance with the API RP 2 Z, and a specially procured high hydrogen level of 11.6 ml/100 g for the additional requirement. Resistance to cold cracking was examined in the following procedures:

(1) The minimum heat input which can prevent cold cracking at less than or equal to 25°C preheat was determined.

(2) The minimum preheat temperature which can prevent cold cracking with heat input less than or equal to 0.7 kJ/mm was determined.

Table 4 shows the Tekken test results for 3" Gr. 60.

The CTS test was also performed with two welding conditions for the same material. One condition was set according to API RP 2 Z as 1 kJ/mm heat input and 3 ml/100 g hydrogen. But the other test was performed with 0.6 kJ/mm and 11.6 ml/100 g to examine the marginal extreme case.

Table 5 shows the CTS test results. The cold cracking did not take place in the API condition, but some cracking occurred in the marginal condition although the cracking was observed only on the fusion line.

At any rate, the Tekken and CTS test results confirmed that the preheat is not necessary for hydrogen consumables which were to be utilized for Mars and Ram-Powell TLP deck construction (i.e. SAW, gas-shielded FCAW, GMAW, and SMAW), and that for high hydrogen consumables (e.g. self-shielded FCAW), cold cracking can be prevented at heat inputs more than or equal to 2 kJ/mm or by preheating at temperature more than or equal to 75°C.

5. Production History

In the order production of the deck plates, the maximum plate thickness was 3" for both grades 60 and 50. For some plates, a through-thickness tensile test was required.

Figure 7 shows the production histograms of the chemical composition in ladle analysis for 24 heats. The carbon contents were low, in the 0.05-0.07 % range, in order to keep low Pcm values of 0.15-0.18 %. Undesirable residual elements such as phosphorus and sulfur were controlled to very low levels to increase the base metal toughness. Phosphorus contents did not exceed 0.005 %, and sulfur contents were less than 0.003 %. The steels were Si- and Al-killed but acid-soluble Al contents were controlled to less than 0.015 % to increase the HAZ toughness.

Figure 8 shows the production histograms of the mechanical properties of the steels which were rolled from those heats into 0.788"-3" plate thicknesses, for Gr. 60 as an example. The tensile test specimens utilized differed according to their thickness levels.

Table 4 Tekken test results

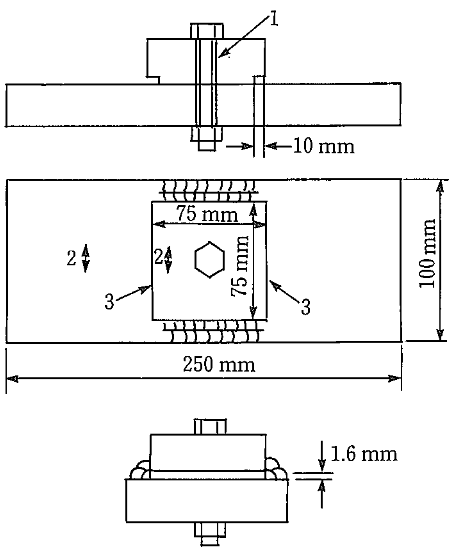
Hydrogen level	Welding condition to prevent cold cracking	
	Heat input at R. T.	Preheat temperature with 0.7 kJ/mm
3 ml/100 g	≦0.5 kJ/mm	≦16°C
11.6 ml/100 g	2.0 kJ/mm	75°C

Table 5 CTS test results

Condition	Heat input	Hydrogen level	Cracking*		
			W. M.	F. L.	HAZ
API RP 2 Z condition	1 kJ/mm	3 ml/100 g	0/6	0/6	0/6
Marginal condition	0.6 kJ/mm	11.6 ml/100 g	0/6	3/6	0/6

Note: * Number of cracked sections / Number of sections examined
** Shape of test specimen:

1: Clearance hole, 13 mm dia.
2: Rolling direction
3: Test welds



For plate thickness not exceeding 1.25", standard 1. 25"-width full thickness plate type specimens were adopted, but for plate thickness more than 1.25", round specimens taken from mid-thickness were used. However, the test results for both yield strength and tensile strength revealed excellent narrow-range histograms without much scatter in spite of their wide range of thicknesses. The shear area percentages in the Charpy impact test at -80°C were more than 50 % with their absorbed energy range of 130-460 joule. Each through-thickness tensile test specimen showed high values in reduction-of-area: in average, 73 % for Gr. 60.

All of the production histograms exhibited high-quality steel properties.

6. Cost Effectiveness of the Steel

The cost effectiveness of the newly developed steel plate for offshore construction can be summarized as follows.

For offshore design engineer:

- Steel selection process is shortened and simplified due to minimization of the steel classification system without cost penalty.
- This enables quicker generation of material take off drawings.

For construction fabricator:

- Number of new welding procedures is minimized.
- Low preheat welding is applicable.
- Steel delivery time is shortened.
- Accordingly, fabrication cost and lead time is minimized.

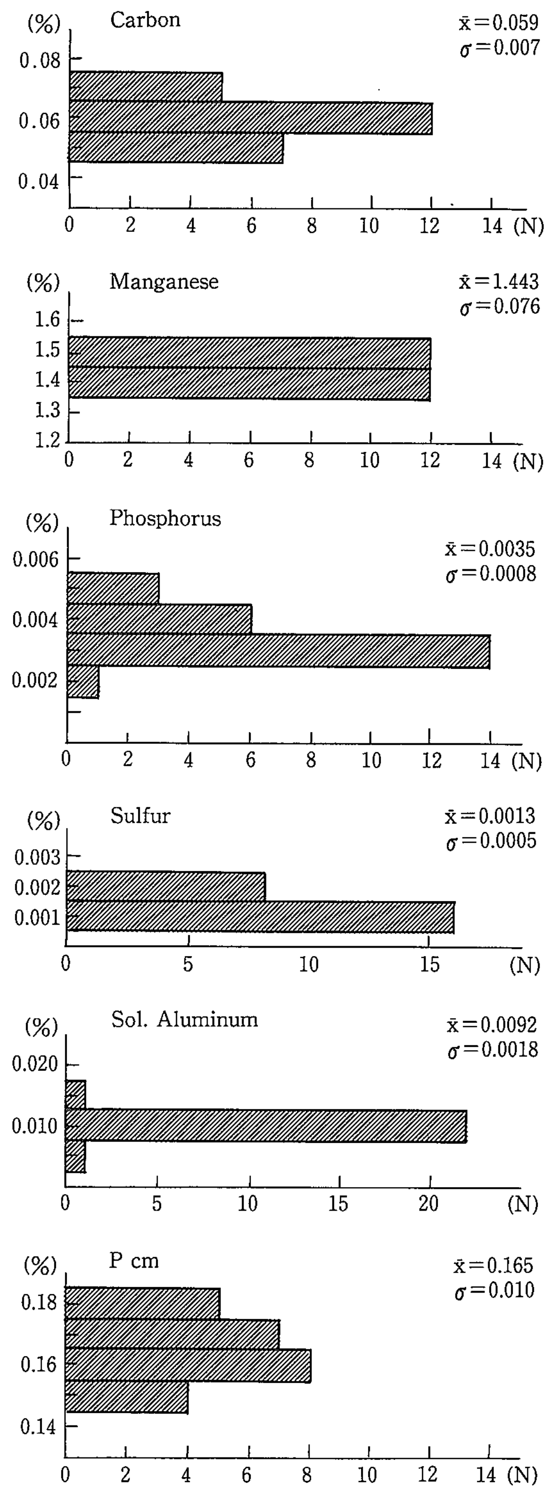


Fig. 7 Production histograms of chemical composition (24 heats)

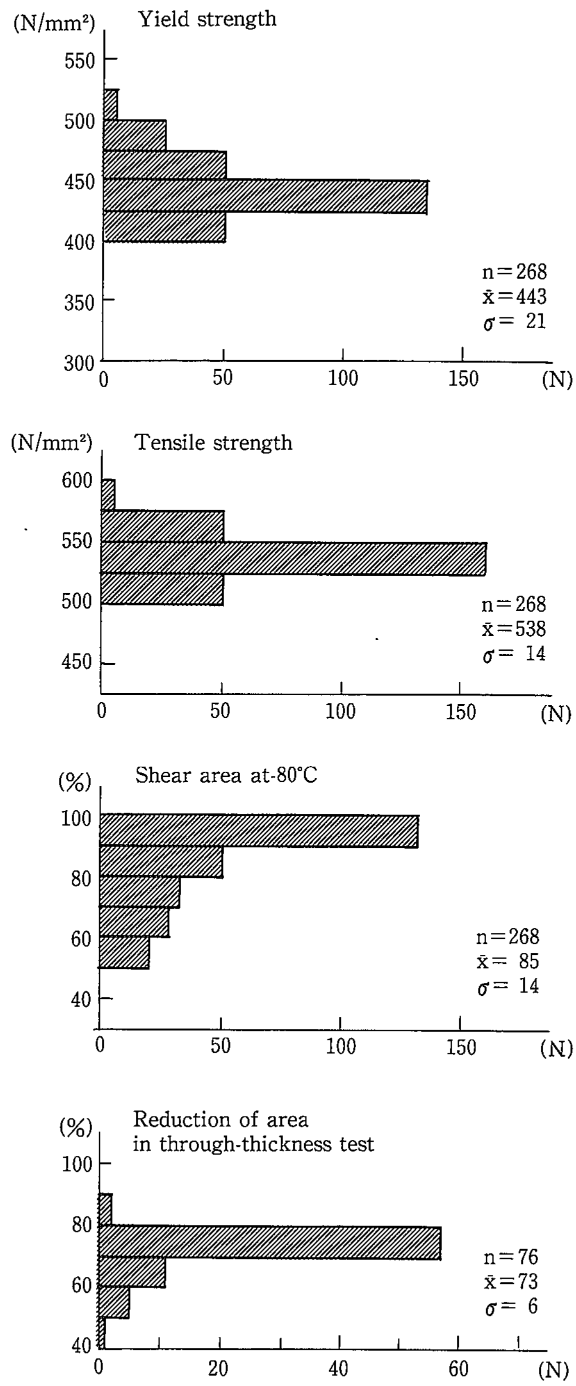


Fig. 8 Production histograms of mechanical properties for Gr. 60 (Thickness: 0.788"-3")

For the end user:

- Total cost saving is enabled with fast-track construction of offshore structure.

7. Conclusions

(1) For the fast-track construction of the Mars and Ram-Powell TLP projects, low Pcm, low Al specialty steel of API 2 W Gr. 60 & 50 was designed and manufactured with the same chemical composition, in order to minimize the steel delivery and fabrication lead time.

(2) Qualification test results in accordance with API RP 2 Z for 3" Gr. 60 and 4" Gr. 50 steels verified their high HAZ CTOD toughness free of local brittle zones.

(3) The production history for the Mars deck steel order revealed very tight property histograms with all steel being verified to have Charpy transition temperatures below -80°C at mid-thickness.

(4) Extremely low carbon equivalent of the steels allowed the implementation of low fabrication preheats, with resultant cost saving.

(5) Cost effectiveness of the steel was verified in the TLP construction in the Gulf of Mexico through the minimization of steel selection processes, number of new welding procedures, fabrication lead time and so on.

Acknowledgment

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