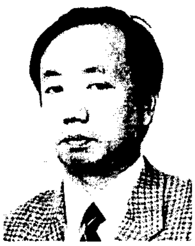
Development of High Performance Steel Plates for Reliable and Economical Steel Structures*



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Synopsis:

Steel structures are now evaluated from the viewpoint of reliability and economy. When the economy is concerned, the cost is evaluated in total, which means that not only the costs related to the fabrication and the weight but also the life cycle cost of the structure is taken into consideration. According to this industrial trend, Kawasaki Steel has developed a new type of high performance steels such as a steel plate having various profiles in the longitudinal direction (LP plate), a new weathering steel which can be used in coastal regions without painting and an extremely-low carbon bainitic steel manufactured on the basis of microstructure-controlling technology, which can be welded without preheating. This paper reviews these high performance steel plates and summarizes technological subjects in the future.

1 Introduction

Steel plates are used as main members of every kind of huge structure and their role not to change in the 21st century. For this reason, high-performance steel plates having properties such as high strength, ultra-heavy gauge, applicability in frozen sea areas and resistance to acid environments, have been developed for every environment.

In addition, various approaches to reducing the total cost of structures have recently been adopted by (1) reducing the weight of steel by inreasing strength without imparing weldability, (2) reducing work load by omitting processes during assembly or reducing preheating during welding, and (3) reducing the maintenance costs of a structure during its usable life. Furthermore, a higher level of reliability of welded structures has also been required.

In light of these points, Kawasaki Steel has conducted various basic studies and used their results to develop new products in each field. This report describes the history of development of these new products and their features along with challenges related to their commercialization.

2 Technical Trends and Research Challenges in Steel Structures

2.1 Fatigue of Welded Joints in Structures

Although the strength of steels for welded structures has been increased, the fatigue strength of welded joints is still low despite the strength of steel plates. This fact has prevented high-strength steels from being used in structures. Causes of the low fatigue strength of welded joints include residual tensile stresses present in welds and stress concentration due to discontinuous shapes. Although measures against the low fatigue strength of welded joints, including stress-relief annealing after welding, hammer peening, grinding, etc., are available, they might not necessarily be the best in terms of economy.

In recent years, it has been shown that it is possible to achieve high fatigue strength in an as-welded condition through the use of martensite transformation expansion in the cooling process of weld metal. As shown in **Fig. 1**, compression residual stresses can be introduced into a weld by using a weld metal of low Ms point, thereby causing transformation expansion to occur at a temperature near room temperature. On the basis of this concept,

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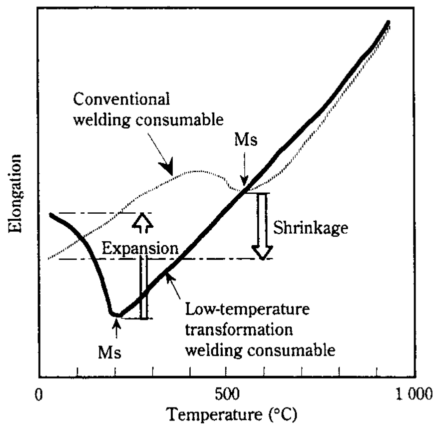

Fig. 1 Relationship between elongation and temperature of weld metal

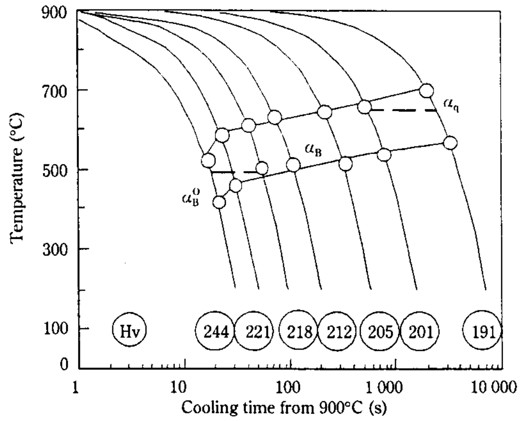

Fig. 3 CCT diagram of extremely-low carbon bainitic steel

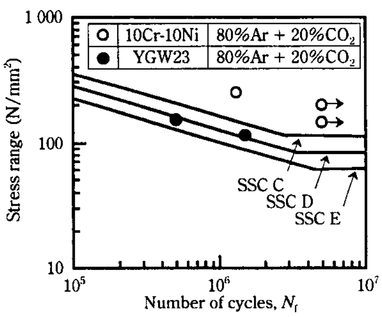

Fig. 2 *S-N* curve of welded joint

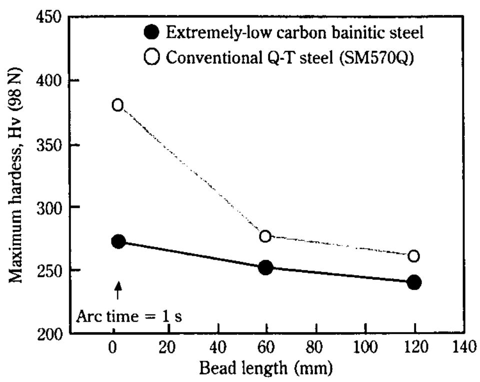

Fig. 4 Results of maximum hardness test

Kawasaki Steel has cooperated with the National Research Institute for Metals (NRIM) in making a new low-transformation temperature welding wire and has been developed a 10Cr-10Ni-base wire. The fatigue strength of welded joints produced by using this wire has improved[1]. This welding material is also effective in improving cold cracking resistance[2]. **Figure 2** shows the fatigue strength of a non-load-carrying cruciform welded joint[3] to which a low-transformation temperature welding material (10Cr-10Ni-base) was applied. The fatigue strength was improved dramatically in comparison with a conventional joint (YSW23). At present, the company is working with NRIM to put this material to practical use.

2.2 New Approach to Reduction of Preheating

As the size of welded structures increases and their manufacturing costs decrease, steels that have high strength and are excellent in toughness, weldability and economy are being demanded. However, increasing tensile results in increasing the carbon equivalent has also increased cold cracking susceptibility due to the hardening of the weld heat-affected zone (HAZ). In order to overcome these problems, the development of high-tensile steels with a low carbon equivalent has been advanced by the application of the TMCP (thermo-mechanical control process) technology which combines controlled rolling and acclelerated cooling.

The company has further developed these concepts and investigated the bainite structure and transformation behavior of extremely-low carbon steels, especially with carbon content of less than about 0.02 mass%.

Figure 3 shows a continuous-cooling transformation (CCT) diagram with deformation of an extremely low carbon-bainitic 0.016%C-1.58%Mn steel. This steel shows the characteristic behavior in which only bainite transformation occurs in a wide cooling range of 0.13 to 23°C/s. The utilization of this behavior enables very thick 570 MPa class high-tensile steel plates to be manufactured without heat treatment.

Figure 4 shows the results of a maximum hardness test for the HAZ obtained through the use of this extremely-low carbon bainitic steel, which was conducted in accordance with JIS Z 3101[4]. For the extremely low carbon-bainitic steel, almost no increase in HAZ hardness was observed in the case of a short test weld bead length with an arc time of 1 s and a Vickers hardness of 268, a very low value compared with 330 to

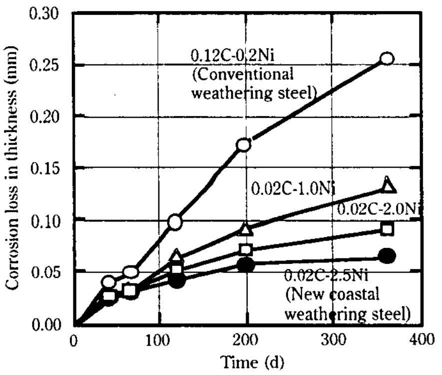

Fig. 5 Effect of Ni content on corrosion curve in seawater spray test (Place: Mizushima Works quay, spray time: 1 h, frequency: twice a week)

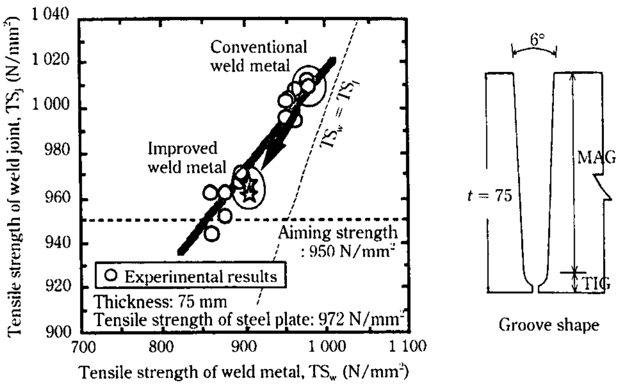

Fig. 6 Relation between tensile strength of weld metal and TIG + MAG weld joint with rectangle specimen in accordance with JIS Z 3121

380 in conventional steel. The use of extremely low carbon-bainitic steel that has this excellent weld hardening resistance has made it possible to completely eliminate the need for preheating even in the welding of very thick 570 MPa class high-strength steel plates with[5)].

2.3 Present State of Weathering Steels and New Steels

Weathering steels (JIS-SMA steels) form dense, stable and protective rust layers on their surfaces in an atmospheric environment and their corrosion rate is reduced to an extremely low level over a long period of time. Utilizing this effect in unpainted weathering steel bridges enables initial painting and repainting to be omitted, thereby contributing to a reduction in the life-cycle cost (LCC). In Japan, the annual demand for materials for steel bridge girders is about 600 000 to 700 000 t. The proportion of weathering steels in this demand has been increasing and is now about 12%.

One of the problems with weathering steels is that stable rust layers rarely form in coastal areas, with the result that the corrosion rate does not decrease. For this reason, the use of unpainted weathering steels was restricted in 1993, by the guidelines of the Public Works Research Institute of Ministry of Construction[6)]. Furthermore, in recent years, similar problems have been pointed out in non-coastal areas were deicing salt is sprayed on roads in winter[7)].

The reasons why stable rest layers are not formed in an environment containing a large amount of chlorides include (1) progress of corrosion due to the deliquescence of chlorides, (2) crystallization (coarsening) of rust, (3) enrichment of Cl at the rust-metal interface of a rust layer, and (4) promotion of formation of Fe_3O_3 and β-FeOOH.

To prevent these actions of chloride, alloying elements such as Ni, Cu, Cr, Mo and P were added to a 0.02%C steel and the effects of these elements were evaluated in a seawater spray test. **Figure 5** shows the effect of Ni content on the corrosion loss in thickness of steels in the seawater spray test. The corrosion loss in thickness decreases with increasing Ni content and, at the same time, corrosion tends to become saturated with an increase in the Ni content. The features of a rust layer of a new weathering steel for coastal areas, which is obtained by adding 2.5% Ni to a 0.02%C steel, are: (1) a high continuity of a dark layer, or an optically isotropic layer, (2) a high proportion of amorphous rust, and (3) a low Cl content at the rust-metal interface of a rust layer. Therefore, Ni suppresses the crystallization (coarsening) of rust in the presence of chlorides and thus functions to suppress the enrichment of Cl at the rust-metal interface.

2.4 Improvement of Performance of Welds by Matching of Steels with Welding

The performance of steel structures is often determined by the performance of welds. In recent years, in order to provide increasingly high performance of welds, it has become necessary to comprehensively develop steel plate, welding materials and welding methods. This subsection describes examples of development related to the welding of an HT980 steel for penstocks for pumped-storage power plants.

In weld metal, the target strength and toughness could be reached by optimizing of the carbon equivalent and lowering the C content which lead to a decraese in cold cracking susceptibility. In order to realize them, the steel plate were matched with welding materials to ensure both the reduction of preheating and the high strength and toughness of the plate[8)].

Furthermore, when the narrow-gap TIG + MAG welding method was applied, the matching of steel plate with welding materials was also examined and, as shown in **Fig. 6**, it was clear that the target welded joint strength could be met even when the weld metal strength was reduced to 900 N/mm^2[9)]. Moreover, a shown in **Fig. 7**, toughness was greatly increased by reducing the

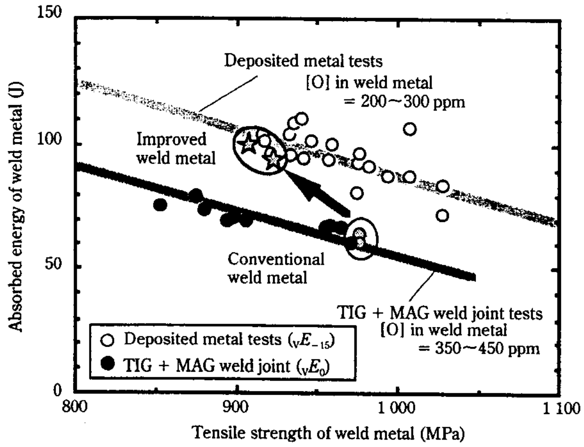

Fig. 7 Relation between tensile strength and Charpy absorbed energy of weld metal

strength of weld metal and lowering the oxygen content. In a narrow-gap TIG + MAG welded joint for which welding materials and welding shield gas composition were optimized, the Charpy absorbed energy[9] was about twice the value of conventional welded joints[10].

Such comprehensive development is very effective in improving the performance of welded joints and it will be necessary to continue to work toward such development in the future.

2.5 Controlling Properties of Weld Heat-Affected Zone

Welding procedures with heat input in a range of 1 to 100 kJ/mm are applied to steel plates for welded structure, and the need for excellent HAZ toughness is also strong with a development to higher strength of steel materials. The basic concepts of HAZ toughness control at Kawasaki Steel are described below. They apply not only to steel plates for shipbuilding and offshore structures, but to steel plates for low-temperature tanks.

2.5.1 Technologies for improving coarse-grain HAZ toughness

The heat-induced deterioration of HAZ toughness occurs in a coarse-grain HAZ. In order to improve this toughness, it is essential to make use of the pinning effect for suppressing the growth of γ-grains. For this purpose, techniques for utilizaing TiN by optimum Ti/N ratio control and REM (O, S) for controlling a higher heating region were established. Furthermore, toughness was improved by combining opitimum Nb content to suppress the formation of upper bainite after transformation and form acicular martensite-austenite constituents, etc.

2.5.2 Technologies for improving toughness in local brittle zone

In multi-layer welding, it is important to improve a

(mass%)

Steel	C	Si	Mn	P	S	Al	Cu	Ni	Nb
TM1	0.07	0.11	1.45	0.010	0.001	0.035	0.26	0.73	0.012
TM2	0.08	0.38	1.46	0.004	0.001	0.033	0.20	0.20	0.025
NM	0.16	0.37	1.49	0.011	0.003	0.017	–	0.16	0.027

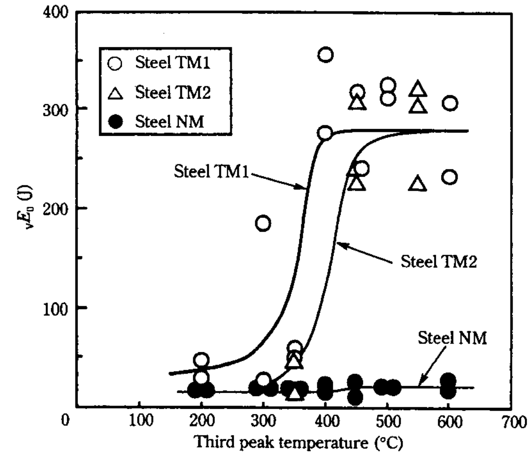

Fig. 8 Effect of the third reheating peak temperature on the toughness of the ICCGHAZ (The first and second reheating peak temperatures of simulated ICCGHAZs were 1 400°C and 800°C, respectively.)

local brittle zones that are formed by multiple heat cycles. In a local reverse-transformation region, especially when the above coarse-grain region is a former structure, the lowering of the Si content shown in **Fig. 8** is effective because this suppresses the deterioration of toughness due to martensite-austenite constiuents[11]. Also, the toughness in a subcritically reheated region is improved by minimizing elements, e.g. Nb, V, that form carbonitrides precipitates.

2.5.3 Technologies applied to steel plates for low-temperature tanks

Steel plates for the storage tanks of LNG (boiling point: −162°C) require a high-level of integrity, which is accomplished by suppressing brittle-crack initiation from welded joints and, in the event of brittle-crack initiation, by stopping cracks in the base metal. In addition, steel plate must become thicker due to the recent trend toward construction of large tanks.

In order to meet such requirements for high strength and toughness of base metal and HAZ toughness, methods for suppressing the formation of martensite-austenite constituents were applied by lowering the C content and adjust the ratios of alloying elements. In an example of a 50 mm thick 9%Ni steel plate developed for use in LNG tanks[12], 0.010% Nb was added and the Si content was lowered to 0.08%. The addition of amount of Nb enables the steel plates strengthened by precipitation to be compatible with the increase in HAZ toughness achieved by the grain refinement shown in **Fig. 9**.

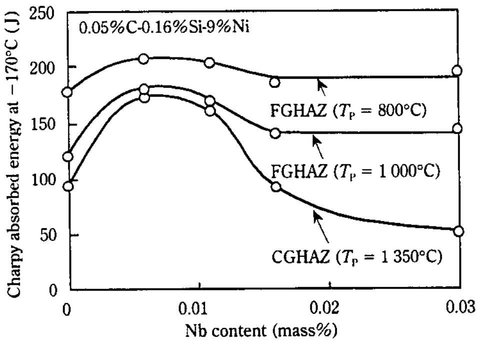

Fig. 9 Effect of Nb content on toughness of synthetic heat affected zones of 9%Ni steel

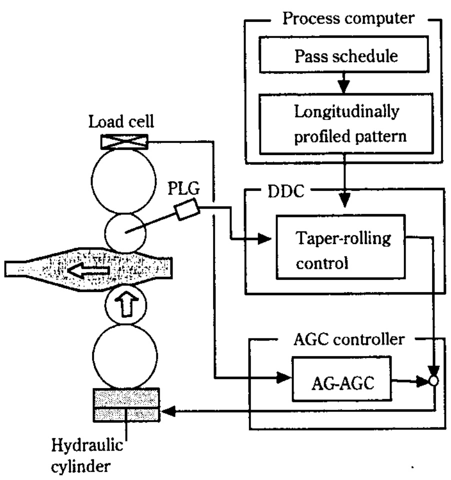

Fig. 10 System configuration for LP plate rolling

2.6 Development of New Process Technologies

LP (longitudinally profiled) plate rolling is a process for manufacturing a steel plate with its thickness continuously varied in the longitudinal direction.

The plate thickness control of LP plates is based on the technology of MAS rolling[13], which involves correcting plate thickness with good accuracy during rolling passes. An outline of a plate thickness control system of LP plates is shown in **Fig. 10**. This system comprises a process computer, which performs pass schedule calculations and determines taper shapes given in each pass; a DDC (direct digital controller), which determines roll opening settings while tracking longitudinal positions; and a hydraulic roll positioning controller, which controls the position of the hydraulic pushdown cylinder[14]. New technologies of controlled cooling, hot leveling and shearing have also been introduced for LP plates[15].

In order to manufacture heavy gauge steel plates by a continuous casting process that permits process omission, the company has developed a technology for applying the forging process to continuously cast slabs, and has found that steel plates with good internal quality can be produced by this technology[16]. Furthermore, the application of the bidirectional forging process, which comprises the application of a forging reduction in the direction of slab thickness after a reduction in the direction of slab width, is effective in crushing and shutting center porosities that are inevitably present in a CC slab and permits the manufacturing of heavy gauge steel plates that have excellent internal quality and mechanical properties[17]. Additionally, in a manufacturing process in which the holding time of slab forging is lengthened in order to reduce the center segregation of a CC slab, it is possible to substantially improve the low-temperature toughness, susceptibility to temper-embrittlement, etc. in the middle position of plate thickness[18]. In a 110 mm thick JIS SCMV4 steel plate to which this process is applied, the value of vTrs in the middle position of plate thickness was greatly improved as shown in **Table 1**.

Table 1 Results of V-notch Charpy absorbed energy at the mid-thickness of 110 mm thick SCMV4 steel

Case	Homogenizing treatment	Forging ratio (%)		vTrs
		Widthwise	Thicknesswise	
1	Not applied			−49°C
2	1 270°C × 14 h	4	21	−76°C
3	1 270°C × 41 h	4	28	−84°C

3 New Products of High Performance Steel Plates and Their Properties

3.1 Steel Plates for Shipbuilding and Offshore Structures

A new product that has come to be used in large quantities in the shipbuilding industry is the LP plate[15]. In 1993, this steel plate began to be used in trans bulkheads of bulk carriers. As shown in **Fig. 11**, it is possi-

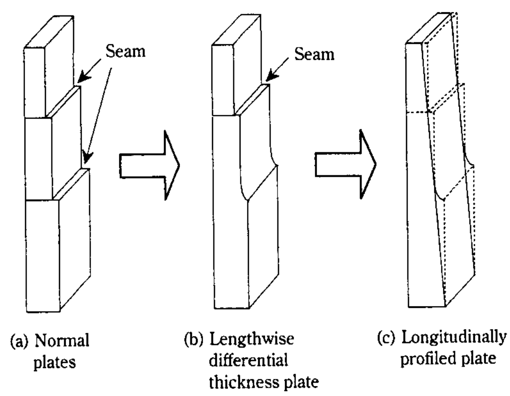

Fig. 11 Example of an omission of seams and reduction of weight suing LP plate

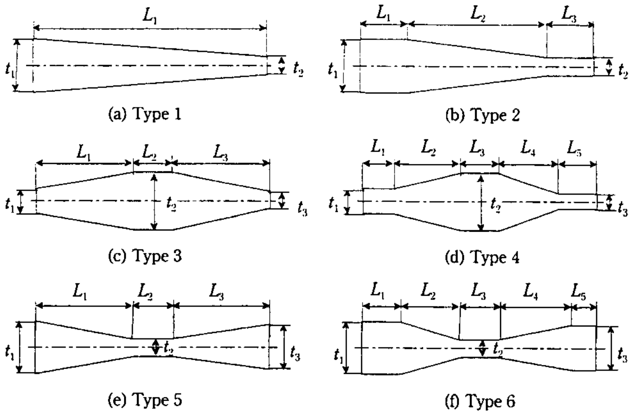

Fig. 12 Various profiles of longitudinally profiled plates

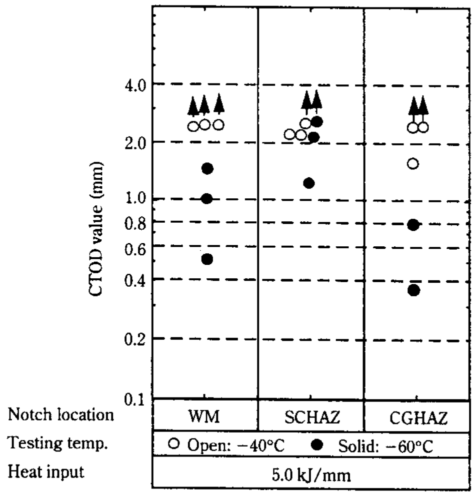

Fig. 13 CTOD test results for SAW welded joints of steel plate developed

ble to reduce the number of welds by using differential-thickness plates in place of normal plates with a constant thickness and it is possible to further reduce the number of welds by using LP plates.

The LP plate shown in Fig. 11 is called Type 1 (**Fig. 12**), recentry Type 2 LP plates have been used in the bottom portion of bulk carriers.

In the shipbuilding industry, there is a great need for thick, high-strength steel plates suitable for large heat input and steel plates that eliminate the need for paint maintenance, and high joint fatigue strength remain to be dealt with[19]. The company intends to continue development in this field.

Incidentally, a 13%Cr-5%Ni-1%Mo steel[20], which is a martensitic stainless steel that was developed for use in the hydrofoils of a jet foil, will become capable of being used in the hydrofoils of a future techno super liner.

For offshore structures, the company has developed a 101.2 mm thick steel plate with YP of 420 MPa class[11]. Recently, the company has also developed a 75 mm thick steel plate that can ensure CTOD (crack tip opening displacement) values of not less than 0.30 mm at −40°C for use in icy waters[21]. This steel was created by adding 1.1%Ni to ensure low-temperature toughness in addition to the already developed HAZ toughness measures such as lowering the content of C, N, Si and P, and the REM-Ti treatment.

Figure 13 shows the CTOD properties of SAW joints with heat input of 5.0 kJ/mm. Very high and consistent values are obtained.

3.2 Steels for Civil Engineering and Bridges

In order to respond to the rationalization of bridge construction, the company is developing steel plates that are effective in raising the efficiency of fabrication and construction.

The application of the manufacturing technology of the extremely-low-carbon bainitic steel described in Subsection 2.2 has enabled thick plates of 570 MPa class steel to be produced in an as-rolled condition (a non-heat-treated condition)[22]. This newly developed steel has Pcm (weld cracking susceptibility) of not more than 0.20 mass% and eliminates the need for preheating work in welding. Furthermore, because this steel plate has excellent low-temperature toughness as mentioned above and does not show deterioration of mechanical properties even when it is water-cooled immediately after heating to not less than 900°C in the line heating process, it has been attracting attention as a steel plate that contributes greatly to the reduction and omission of processes in fabrication and construction.

The use of weathering steels is increasing as an effective means of reducing the LCC of bridges and the company has been developing new steel plates on the basis of the extremely-low-carbon bainitic steel.

By adjusting the amounts of alloys such as Mn, Cu, Ni and Cr to the ranges stipulated by JIS, the company has developed a non-heat-treated extremely-low-carbon bainitic weathering steel SMA570WTMC for rural areas[23]. This new steel has better weldability and workability than conventional steels.

Furthermore, the company has developed a weathering steel for coastal areas to which Ni is added in an amount of 2.5 mass% that can be used even in districts where the air-borne salinity is more than 0.05 mdd (mg · dm^{-2}/d). Like the above weathering steel for rural areas, this steel is a non-heat-treated extremely-low-carbon bainitic steel. Steel plates of 400, 490 and 570 N/mm^2 class have been developed[24].

An outline of the series of these non-heat-treated extremely-low-carbon bainitic steels is given in **Table 2**.

In the construction of the Akashi Kaikyou Bridge, which is a very long suspension bridge, a large amount of HT780 steel was used to stiffen and reduce the weight

Table 2 Production data of extremely-low C bainitic steel plates

Steel	Thickness (mm)	YS (N/mm²)	TS (N/mm²)	vE (J)	Pcm (%)
TS570 Gr. steel SM570TMC	83	(≧420) 496	(≧570) 642	(≧47) 314 (−5°C)	0.18
Weathering steel SMA570WTMC	75	(≧430) 459	(≧570) 615	(≧47) 292 (−5°C)	0.16
2.5%Ni containing weathering steel SMA400CW-MOD	25	(≧235) 395	(≧400) 499	(≧47) 388 (0°C)	0.11
SMA490CW-MOD	25	(≧355) 447	(≧490) 568	341 (0°C)	0.15
SMA570W-MOD	25	(≧450) 514	(≧570) 664	322 (−5°C)	0.15

( ); Requirement of JIS G 3106 and 3114

of girders. In this case, the development of at HT780 steel that meets preheating temperatures of not higher than 50°C was required to increase the efficiency of welding and to prevent thermal deformation caused by preheating. In this steel, the Pcm value is reduced to 0.23 mass% or less by adding Nb while lowering the B content to a minimum, whereas Ceq is not less than 0.45 mass% in order to ensure the strength of joints[25]. When a y-groove weld cracking test was conducted in an environment with a temperature of 30°C and humidity of 80%, a 34 mm thick steel plate achieved temperatures preventing weld cold crack up to 50°C. In the Charpy impact test at −40°C, this steel had high toughness values exceeding 200 J.

Since the LP plate permits a rational plate thickness design suited to required sectional forces when used in a structure, the use of this plate can reduce costs through reduction in weight, omission of plate-joining welding, and other means.

Kawasaki Steel started manufacturing the LP plate earlier than any other steel company and introduced the new technologies described in Subsection 2.6. As shown in Fig. 12, it is possible to manufacture six types of LP plates that have various profiles. It is possible to manufacture all the JIS steel grades of LP plate specified in the Specifications for Highway Bridges. The company produced LP plates for bridges in the fall of 1994 for the first time in Japan. As of April 2000, it had shipped a total of about 13 000 t of LP plates for bridges and shipbuilding.

As steel materials for the penstocks of pumped-storage power plants, high-tensile steels including HT780 steel have so far been used. To meet large-capacity design of power plants and an increase in head, application of an HT980 steel of higher strength is being examined. Since the penstocks are welded in a tunnel, steels of low preheating temperature during welding are required. In order to meet these needs, the company has carried out comprehensive development of an HT980 steel plate including welding materials and developed 50 mm and 75 mm thick HT980 steel plates of low preheating temperature type, SMAW, SAW, MAG and TIG welding materials[10].

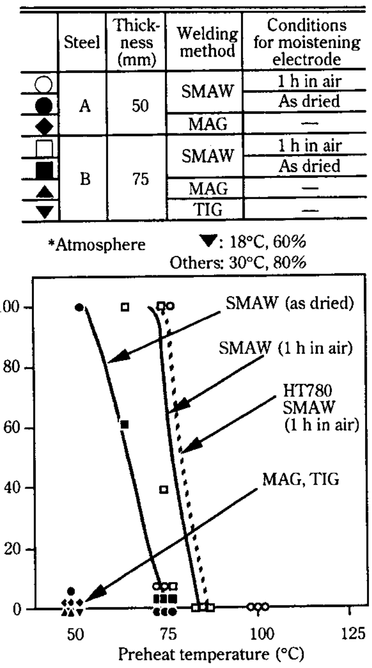

Fig. 14 Results of the y-groove weld cracking test

A y-groove weld cracking test (air temperature 30°C, humidity 80%) was conducted with various combinations of the developed steel plates and welding materials. As shown in **Fig. 14**, a crack-preventing temperature of 75°C was obtained with SMAW, and up to 50°C was obtained with MAG and TIG. Thus, it was confirmed that the HT980 steel has cold cracking resistance almost equal to that of the usual HT780 steel. With respect to fracture toughness, results of a large-scale test reveal that the base metal can arrest brittle fracture at 0°C, which meets the type A standard of WES3003, and that welds have the ability to block the occurrence of brittle fracture from a surface defect 30 mm in length and 10 mm in depth under the conditions of applied stress of 400 N/mm² and 0°C.

3.3 Building Structural Steels

Vibration-damping design which uses vibration dampers is receiving attention as a technique to improve the seismic-resistance of buildings. Many hysteresis-type dampers of attenuation strain made of low yield point steels have been developed that are stable, economical and durable. These dampers suppress the vibration response of main structures of columns and beams by converting the vibration energy of an earthquake into the plastic energy of steel materials.

The company has developed "RIVER FLEX" steel plates with yield strength classes of 100 N/mm^2 and 235 N/mm^2 for vibration dampers and is bringing them to the commercial stage[26].

In the 100 MPa class steel plates, Ti and Nb are added to a nearly pure iron composition and grains are coarsened by appropriate rolling and heat treatment. On the other hand, in the 235 MPa class steel plates, C is added in an amount up to about 0.05% and the grain size is controlled according to the range of yield strength by selecting optimum manufacturing conditions.

3.4 Steel Plates for Pressure Vessels and Storage Tanks

In the field of low-temperature storage tanks, the company has developed a 50 mm thick high-toughness 9%Ni steel plate to meet to the toward increasingly larger aboveground LNG storage tanks. High fracture toughness values are obtained in welded joints by lowering the Si content and adding a trace amount of Nb as shown in Subsection 2.5[12].

Figure 15 shows the results of a CTOD test of three types of welded joints. High values of 0.49 mm or more were obtained even at −170°C. In the duplex ESSO test of the fusion-line of joints made by vertical welding, brittle cracks which propoagated through the crack-stater plate were arrested immediately after breaking into the fusion lines, and the Kca values, which were not less than 268 $MPa \cdot m^{1/2}$, were satisfactory.

The company also developed a 150 mm thick heat-treated steel plate as a steel material for boilers and pressure vessels in medium- and ordinary-temperature zones of not more than 350°C. This new steel material is stronger and more weldable than the SBV2 steel, and replaces it in accordance with JIS G 3119. The target values of properties of this new steel plate are shown in **Table 3**. In this steel plate, which was obtained by further developing the SPV 490 steel in accordance with JIS G 3115, alloying elements are optimized to ensure in the range from room temperature to 350°C even after three post-weld heat treatments. Excellent weldability was also obtained[27].

In the field of acid-resistant pressure vesseles, the company has been developing high performance steel materials through the investigation of HIC (hydrogen-induced cracking) and SOHIC (stress-oriented HIC)[28].

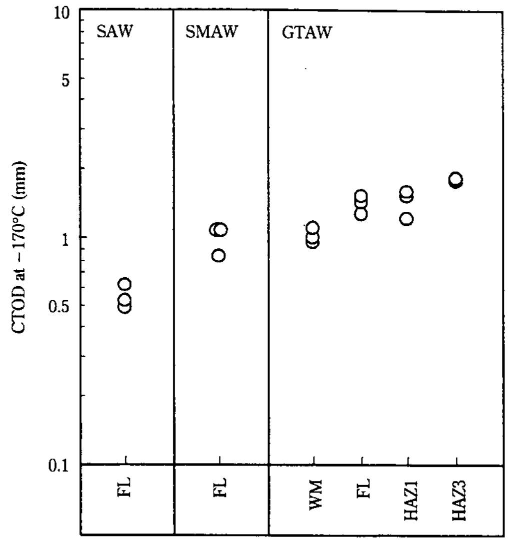

Fig. 15 Resistance to brittle fracture initiation of 9% Ni steel welded joints indicated by CTOD test (WM: Weld metal, FL: Fusion line, HAZ1: HAZ 1 mm, HAZ3: HAZ 3 mm)

Table 3 Target values for the advanced SPV490 steel plate

Item	Target value
Thickness (mm)	Maximum 150
Carbon equivalent (mass%)	Ceq*1 ≦ 0.52
Weld cracking parameter (mass%)	Pcm*2 ≦ 0.27
PWHT cracking parameter (mass%)	ΔG*3 < 0
Tensile strength (MPa)	≧ 610 (At RT~350°C after triple PWHT)
V-notch Charpy absorbed energy of base metal (J)	$vE_{-30°C}$ ≧ 47

*1 Ceq = C + Mn/6 + Si/24 + Ni/40 + Cr/5 + Mo/4 + V/14 (mass%)
*2 Pcm = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + 5B (mass%)
*3 ΔG = Cr + 3.3Mo + 8.1V − 2 (mass%)

These materials are a 127 mm thick ASTM A516-70 steel plate and a 50.8 mm thick ASTM A841 cl.1 steel plate[28]. In the A841 cl. 1 steel plate, the application of TMCP form a structure composed almost exclusively of bainite, which provided not only good HIC characteristics, but also a minimum critical stress exceeding 0.9 SMYS in a tension-type SCC test in the solution A in accordance with NACE TM0177-96.

4 Concluding Remarks

With the increasing level of needs for steel plates, there has been demand for the development of new steel plates that minimize the LCC of structures, and for new products that suit the performance based design whose introduction has recently been pushed forward. On the other hand, there are many problems yet to be solved, such as problems of fatigue of welded joints and corrosion in various environments. In the 21st century, undoubtedly steel plates will continue to be used as main members of large structures. For its part, Kawasaki Steel will continue working to develop better and stronger steels.

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