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Development of Thermo-Mechanical Control Process (TMCP) and High Performance Steels in JFE Steel

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Abstract:

Thermo-mechanical control process (TMCP) is one of microstructural control techniques, combining controlled rolling and controlled cooling, to obtain excellent properties of steel plates, such as high strength, excellent toughness and weldability. JFE Steel has continued in an effort to develop TMCP technologies, ever since JFE Steel started operation of the accelerated cooling equipment, OLAC™ (On-Line Accelerated Cooling), in the plate mill at West Japan Works (Fukuyama) in 1980, which was the first industrial accelerated cooling system in the world. TMCP technologies in JFE have kept on evolving to ***Super****-OLAC-A in 2011 to achieve super rapid cooling rate and uniform cooling all over the plate, HOP™ (Heat-treatment On-line Process) and* ***Super****-CR enabling quite unique microstructural control to the plate. NEO press™ has also installed at West Japan Works (Fukuyama) in 2011 to produce high strength and heavy wall thick linepipes for deep water off-shore pipeline projects. This paper describes features of those leading facilities and the recent development in TMCP with some examples of new products in JFE Steel.*

1. Introduction

In response to progress in design and manufacturing technologies for welded steel structures and requests for total cost reduction, high strength and high workability (weldability) are constantly required in steel plates used in welded steel structures. In recent years, structures have become larger in scale and their use environments have become increasingly severe, while at the same time, there has also been a tendency to prioritize safe and secure design. As a result of these trends, more advanced and complex performance requirements are now placed on steel plates. In order to satisfy these requirements, precise material design technology and advanced manufacturing technology have become essential.

Higher performance in steel plates is supported by alloy design technology and ceaseless progress in the thermo-mechanical control process (TMCP). It can be said that the development of TMCP is a result of the pursuit of process continuation and on-line manufacturing technologies. The combination of controlled rolling technology and controlled cooling technology in TMCP has made it possible to satisfy both high strength and high toughness, which had been impossible without offline heat treatment in the past. Since JFE Steel applied OLAC™ (On-Line Accelerated Cooling), which was the world's first online accelerated cooling device, to a commercial plate manufacturing line, the company has pursued high performance in the cooling equipment through tireless technology development [1, 2]. Continuation with the tempering process was also achieved by JFE Steel's HOP™ (Heat treatment On-line Process) [2], realizing online production of high strength plates. Moreover, the new concept of continuation of the controlled rolling process was proposed [3], and the *Super*-CR intensive cooling device located close to the rolling mill was applied practically. The continuation of these processes also responds to the needs for higher productivity and shorter delivery times, which are always required in industrial products. On the other hand, improved weldability is also demanded in plates for use in welded steel structures. The problems of weld cold cracking performance and deterioration of the toughness of the heat affected zone (HAZ) were also solved by producing high strength plates with a low alloy composition by applying TMCP.

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The performance of plates for large heat input welding was greatly improved by progress in precipitate and inclusion control technology, but this is also based on a low alloy design preconditioned on TMCP.

This paper reviews the progress of plate manufacturing at JFE Steel, centering on technological innovation in TMCP, and also presents an overview of high performance steel plates used in various fields that were developed by maximizing the use of these process technologies.

2. Progress of Plate/Pipe Manufacturing Processes in JFE Steel

2.1 TMCP Technologies for Steel Plates in JFE Steel

As a result of the development of an original cooling technology, which is a core technology of TMCP, JFE Steel commercialized the world's first practical on-line accelerated cooling system (OLAC^{TM}) for plates at West Japan Works (Fukuyama) [1] in 1980. In 1998, the company commercialized the new *Super*-OLAC^{TM} accelerated cooling technology, which simultaneously achieves both ultra-high speed cooling and uniform cooling over the entire plate [2]. This technology was applied at the three plate mills at West Japan Works (Fukuyama) and (Kurashiki) and East Japan Works (Keihin), and contributed to production of high performance steel plates, including steel for ultra-large heat input welding and aseismic steel pipes [3]. This cooling technology was also applied to the hot strip mill (*Super*-OLAC-H [4]) and the shape steel mill (*Super*-OLAC-S [5]), realizing large reductions in alloying elements, improved weldability and improved formability. In 2004, JFE Steel introduced the world's first on-line induction heating device, HOP^{TM} [6]. Use of HOP in combination with cooling control by the *Super*-OLAC realized on-line heat treatment of high strength, high toughness steel plates [3, 7], which had mainly been produced by off-line quenching and tempering in the conventional process. **Figure 1** is a schematic illustration of microstructure control by induction heating technology.

In 2011, JFE Steel developed the *Super*-OLAC-A as a further evolution of the *Super*-OLAC in order to respond to the more sophisticated property requirements of recent years [8]. **Figure 2** shows the layout of the on-line accelerated cooling and heat treatment facilities at the West Japan Works (Fukuyama) plate mill.

Super-CR was also commercialized as a technology that enables high efficiency (high productivity) in controlled rolling, which is also one of the core technologies of TMCP, and was applied at East Japan Works (Keihin) in 2009. In addition to achieving high productivity in controlled rolling, use of the *Super*-CR in combination with the *Super*-OLAC, as shown in **Fig. 3**, enables 2-stage cooling, thereby enhancing the degree of freedom in the TMCP process [8].

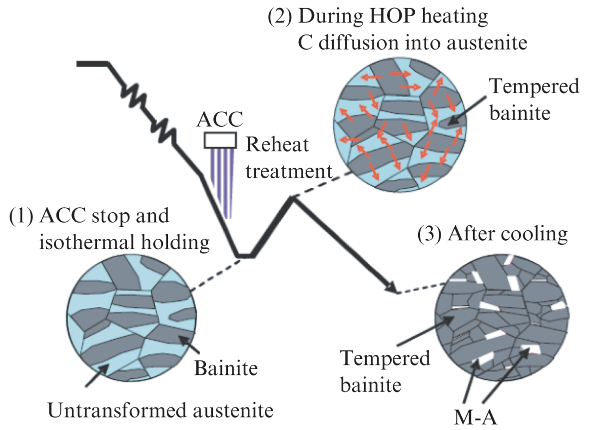

Fig. 1 Microstructure control by induction heating technology

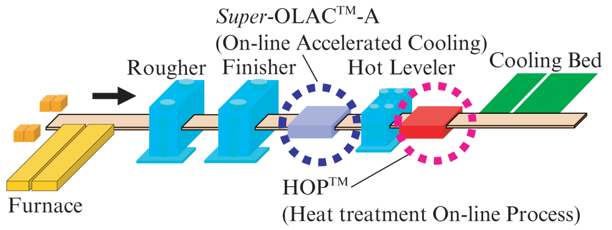

Fig. 2 Layout of on-line accelerated cooling and heat-treatment facilities

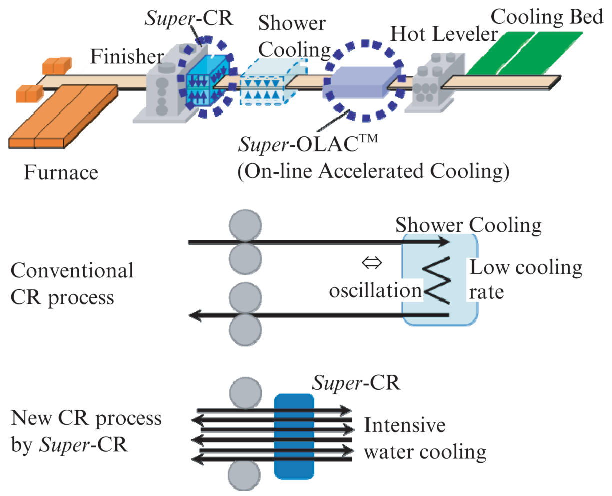

Fig. 3 Improvement of productivity in controlled rolling by *Super*-CR

2.2 Production Process for High Strength, Heavy Wall Thickness Steel Pipes in JFE Steel

The growth of energy demand in recent years has led to increased development of new energy sources

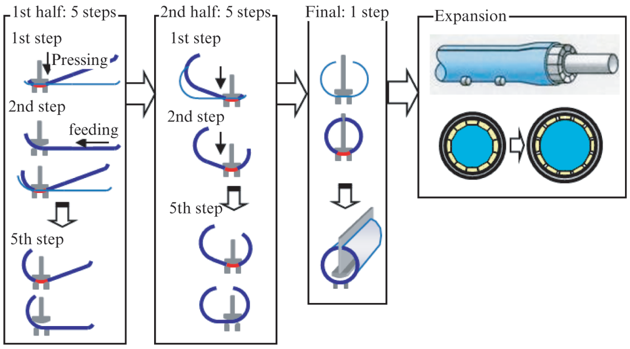

Fig. 4 Schematics illustration of high productivity process of large diameter pipe by high productivity press bending

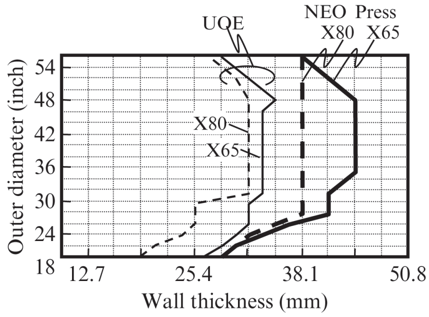

Fig. 5 Available size range of SAWL pipe

such as deep sea fields, *etc*., together with long distance transportation of gas and oil exceeding 1 000 km from the producing region to the consuming region. Because the operation pressure of pipelines has been increased to enable efficient transportation of large volumes of product over these long distances, demand for high strength, heavy wall thickness steel pipes that can withstand those pressures has also increased. Pipes are also laid in deep waters with depths exceeding 2 000 m, such as the Mediterranean Sea and Black Sea, in order to shorten the transportation distance, resulting in increased application of heavy wall thickness pipes to prevent pipe collapse due to water pressure.

In addition to the UOE pipe-making method, which has a long history, JFE Steel developed a new press bending method which makes it possible to produce thicker wall and smaller diameter pipes [9]. A NEO Press™ using this press bending method was installed at West Japan Works (Fukuyama), and the high productivity process for heavy wall thickness and high strength steel pipes shown in **Fig. 4** was established [10].

Development of the high productivity press bending method resulted in about a 3-fold increase in production efficiency in comparison with the conventional press bending method, while reducing the press capacity to 1/7 of that with the UOE method. The available size range of JFE Steel products was also expanded, increasing the maximum outer diameter by 1.2 times, as shown in **Fig. 5** [10].

3. Development of High Performance Steel Products

3.1 Steel Plates for Shipbuilding

Great progress is being achieved in both steel plates for shipbuilding and their use technologies as a result of changes in ship hull structural design in response to more stringent environmental regulations and needs for high efficiency and reduced fuel consumption accompanying the increased maritime transport of recent years.

The trend toward even larger-scale container ships continues unabated, with container ships exceeded 20 000 TEU being planned in 2020. This trend toward upscaling has created needs for heavier wall thickness and higher strength materials for use in container ships, and in 2017, JFE Steel developed a YP460 MPa class crack-arrestability steel with a plate thickness of 100 mm. From the viewpoint of safety against brittle fracture of the strength deck of large-scale container ships, brittle crack arrestability is required in YP460 MPa class steel plates with thicknesses exceeding 50 mm in container ships contracted for construction after January 2014. JFE Steel realized high arrestability, even in YP460 MPa class steel plates with the world's heaviest thickness of 100 mm, by application of an original texture control technology that increases the crystal orientations which resists crack propagation in the plate center-of-thickness. This was possible by applying the *Super*-OLAC-A TMCP technology, which enables precise control of the heating temperature and rolling temperature in addition to refinement of the crystal grain size. **Table 1** shows the chemical composition of the developed YP460 MPa class steel for shipbuilding, and **Table 2**, **Table 3** and **Fig. 6** show examples of the Charpy impact properties, CTOD performance and arrestability of the developed steel, respectively. The developed steel complies all the requirements of low temperature toughness, CTOD characteristics and arrestability of the base material of high strength, Grade E hull structure steel.

JFE Steel also developed a manufacturing system for large heat input welding specification, high arrest toughness specification YP355 to YP460 MPa class extra-heavy steel plates to respond to the complex, sophisticated requirements placed on steel plates used in container ships [11, 12].

In addition to the "material arrestability" approach described above, JFE Steel is also developing technologies which secure high brittle crack arrestability by structural design, that is "structural arrestability."

Table 1 Chemical composition of developed YP460 MPa class steel plate for container ship

Steel	C	Si	Mn	Others	*Ceq* (IIW)	*P*cm
Developed	0.06	0.15	1.93	Cu, Ni, Cr, Nb, Ti	0.47	0.20
Specification of EH47-BCA (IACS UR W31)	≦0.18	≦0.55	0.90 −2.00		≦0.55	≦0.24

Ceq (IIW) = C + Mn/6 + (Cr + Mo + V) /5 + (Ni + Cu) /15
*P*cm = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + 5B

Table 2 Tensile test and Charpy impact test results of developed steel plate

Steel	Thickness (mm)	Direction	C		L
		Position	YP (MPa)	TS (MPa)	vE_{-40} (J)
Developed	100	1/4t	483	594	350
		1/2t	472	585	293
Conventional	60	1/4t	523	645	308
Specification of EH47 (IACS UR W31)			≧460	570-720	≧75

YP: Yield point, TS: Tensile strength,
vE: Charpy absorbed energy

Table 3 CTOD test result of developed steel plate

Specimen size	Direction	Temperature (°C)	CTOD (mm)
B×B (B = 100 mm)	L	−10	0.89 (δ^M_u) 1.59 (δ^M_u) 2.81 (δ^M_u)

CTOD: Crack tip opening displacement

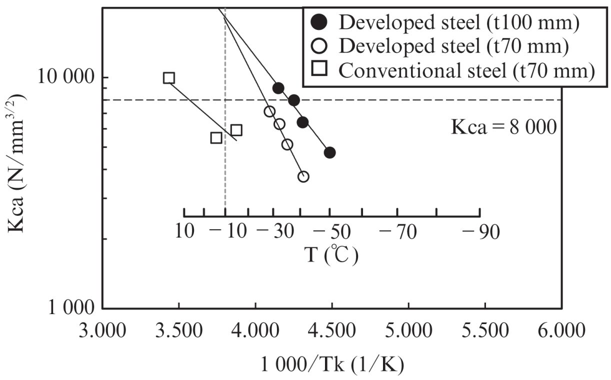

Fig. 6 Results of temperature gradient type standard ESSO test

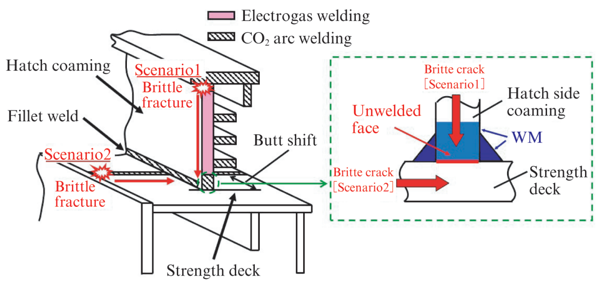

Fig. 7 Brittle crack arrest by structural arrest design

Structural arrestability design, as shown in **Fig. 7**, is a technique for arresting brittle cracks by utilizing a discontinuity in a T-joint between the hatch side coaming and strength deck. The effectiveness of this technique has been demonstrated experimentally. Since it is possible to arrest brittle cracks by using a welding consumable with appropriate low temperature toughness together with a conventional steel plate, this can be considered to be a rational design approach.

Against the trend of increasing demand for LNG in Asia, attention has been focused on gas carriers linking Asia with the United States, which has established an LNG supply system as a result of the "shale gas revolution." The design of Neopanamax (or New Panamax ships), meaning the largest class of ship that can pass through the Panama Canal following completion of expansion work in 2016, has heightened the need for steel plates with high strength, which can contribute to weight reduction.

Medium thickness (up to 50 mm) YP460 MPa class high strength steel plates produced by JFE Steel utilizing TMCP technology have already been applied practically. In the developed steel, both the strength and toughness requirements for welds are satisfied by controlling the HAZ to the optimum microstructure by using the *Super*-OLAC-A and the JFE EWEL™ welding technology, which minimizes deterioration of HAZ toughness. This plate was applied in a 164 700 m^3 LNG carrier commissioned in 2016 as the world's first medium thickness TMCP type YP460 MPa class high strength steel plate, and also made an important contribution to high productivity in ship construction by enabling application of high productivity large heat input welding.

3.2 Steel Plates for Building Structures

The high-rise buildings of recent years are characterized by longer spans and increasingly complex structures accompanying "mixed-use" development, in

Table 4 Lineup of HBL™ steel plate for building structure

Grade	Thickness (mm)	YS (MPa)	TS (MPa)	YR (%)	vE_0 (J)
HBL 325	40 ≦ t ≦ 100	325-445	490-610	≦ 80	≧ 27
HBL 355	40 ≦ t ≦ 100	355-475	520-640	≦ 80	≧ 27
HBL 385L	12 ≦ t ≦ 19	385-505	550-670	≦ 80	≧ 70
HBL 385	19 ≦ t ≦ 100				
HBL 440	19 ≦ t ≦ 100	440-540	590-740	≦ 80	≧ 70
HBL 630L	12 ≦ t ≦ 40	630-750	780-930	≦ 85	≧ 70

YS: Yield strength, YR: Yield ratio

which commercial space, offices and hotel facilities are included in the same structure. Therefore, with demand for high strength, heavy gauge steel products, these trends have heightened the need for high performance steel products in steel plates for building structural use. The requirements for plates used in building structures include not only a low yield ratio (yield strength/tensile strength ratio) and high toughness, which are important from the viewpoint of earthquake resistance, but also excellent weldability.

JFE Steel developed and commercialized the HBL™ Series of TMCP type low yield ratio, high tensile strength steel plates with excellent earthquake resistance for building structural use in a wide range of strength grades and plate thicknesses. **Table 4** shows the lineup of HBL™ steel plates.

The company developed HBL385 as a TMCP steel of tensile strength (TS) 550 MPa grade that provides a good balance of economy, earthquake resistance and weldability, and led the industry in obtaining approval from the Minister of Land, Infrastructure, Transport and Tourism (MLIT) in 2002 [13, 14].

HBL440 was commercialized as a TMCP steel of TS590 MPa class with thicknesses of 19 to 100 mm for use in ultra-high-rise buildings, and offers a combination of high strength, high earthquake resistance and excellent weldability. This plate was developed and applied practically as a result of strict control of the controlled rolling conditions and the excellent temperature control of the *Super*-OLAC, and was approved by the Minister of MLIT in 2013 [15, 16].

In HBL630, excellent mechanical properties of the base metal, together with outstanding weldability and weld toughness as a steel for building structural use, are achieved by utilizing TMCP and HOP to control the microstructure of the steel plate to a multiphase microstructure consisting of a main microstructure of bainite and fine M-A (Martensite-Austenite constituent) (Fig. 1). HBL630 was approved by the Minister of MLIT in 2009 [17].

High strength steel plates for building structural use are frequently used in four-side box columns, and high productivity submerged arc welding (SAW) or electroslag welding (ESW) is applied in the assembly process. These are large heat input welding methods, as the heat input in SAW is 600 kJ/cm and the maximum heat input in ESW reaches as much as 1 000 kJ/cm, which may cause remarkable deterioration of HAZ toughness if no special measures are taken in the steel material. JFE Steel commercialized high HAZ toughness steels in grades HBL325 to HBL440 by applying the JFE EWEL technology for improvement of HAZ quality in large heat input welding [18]. On the other hand, comparatively small heat inputs are used in column-to-column site welding. Since weld cracking due to hardening of the HAZ is a concern in small heat input welding, TMCP technology is applied and the chemical composition of the steel is optimized in the HBL Series.

Application of these steel materials to built-up (welded) H-shapes, square steel tubes (cold-press formed columns) and circular steel tubes is being promoted, and outstanding earthquake resistance, even in cold-formed steel tubes, has been confirmed in the HBL Series, which realizes an excellent low yield ratio as a mechanical property of the base material [14].

3.3 Weathering and Corrosion Resistant Steels

In order to reduce the life cycle cost (LCC) of bridges, which are used over extended periods of time, unpainted weather steel plates that do not require painting at the initial time of construction or during repairs, are used in approximately 20 % of all bridges in Japan [19]. On the other hand, high durability painted steel plates or Ni added weathering steel with high salt resistance is used in regions with high concentrations of airborne salt, such as areas near the coastline and environments where deicing salt is used on roads in wintertime [20, 21]. However, there have also been strong requests for reduction of LCC in these severe corrosion environments, as repainting is necessary and the use of high weathering resistance steels increases the initial material cost.

In response to those requests, JFE Steel developed and commercialized the EXPAL™ (EXtended PAint Life) steel plate, which enables long-term use while reducing the frequency of repainting, even in high salinity environments where painting is essential [22, 23]. As an alternative to expensive Ni added weathering steel, JFE also commercialized LALAC™-HS, which is based on the steel composition in JIS G 3114 (SMA) and has the distinctive feature of addition of trace amounts of corrosion resistance elements to achieve high corrosion resistance without addition of Cr, which is thought to reduce corrosion resistance in high salinity environments, while also holding Ni addition to a low level [24, 25].

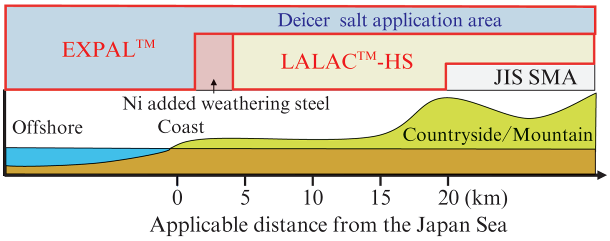

Fig. 8 Applicable area of EXPAL™ and LALAC™-HS

In EXPAL, corrosion of the steel plate itself and deterioration of the paint film are suppressed by adding multiple corrosion resistance elements to the steel, resulting in the formation of a dense protective rust layer on the steel surface, which also electrically suppresses penetration of salt to the surface of the steel substrate. In LALAC-HS, a weathering property (atmospheric corrosion resistance) substantially equal to that of the conventional Ni added weathering steel was successfully obtained by the dense protective rust formed by composite addition of corrosion resistance elements.

Both EXPAL and LALAC-HS are steel plates with excellent cost performance which provide high corrosion resistance, while excellent weldability on the same level as that of general steel for welded structures is secured by use of TMCP technology. **Figure 8** shows the applicable areas of EXPAL and LALAC-HS.

Corrosion is also a serious problem in ships, as it reduces safety and shortens the life of ships. In crude oil tankers, severe pitting corrosion of the bottom plates of the cargo oil tanks is caused by the salt water contained in the crude oil, while general corrosion of the upper deck is caused by repeated wetting and drying due to day-night temperature changes in a mixed atmosphere consisting of the exhaust gas used for explosion prevention and hydrogen sulfide that evolves from the crude oil [26]. Although ship ballast tanks are painted, underfilm corrosion occurs between the paint film and steel due to the severe corrosion environment by seawater [27], and in bulk carriers used to transport coal, local corrosion occurs in the cargo holds as a result of corrosion by dilute sulfuric acid originating from the coal [28]. Improvement of corrosion resistance is required due to the concern that these types of corrosion may reduce the structural strength of ships.

As corrosion-resistant plates for the cargo oil tanks of crude oil tankers, in 2008, JFE Steel developed JFE-SIP™-OT1 as a corrosion-resistant steel for bottom plates and JFE-SIP™-OT2 as a corrosion-resistant steel for upper decks [29]. JFE-SIP-BT for use in ship ballast tanks was also developed in 2008 [30], and JFE-SIP™-CC for the cargo holds of coal carriers was developed in 2014 [31, 32]. **Figure 9** shows the applicable parts of these steels. The protective corrosion products formed by the action of the alloying elements in these corrosion-resistant steels suppresses pitting of the bottom plates and general corrosion of the upper decks of cargo oil tanks, underfilm corrosion of ballast tanks and local corrosion of coal cargo holds.

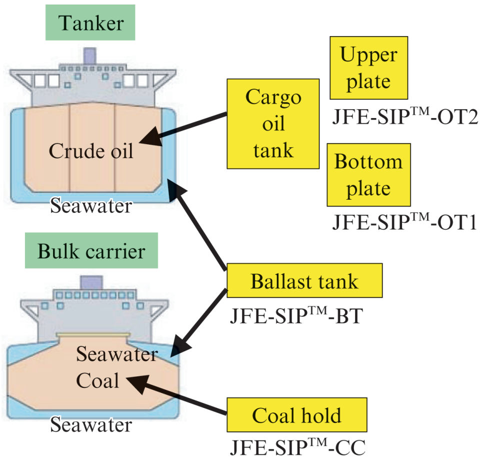

Fig. 9 Applicable part of corrosion resistant steels for shipbuilding

In particular, in 2010, the International Maritime Organization (IMO) established performance standards for the cargo oil tanks of crude oil tanker, requiring either painting or use of corrosion-resistant steel. The above-mentioned JFE-SIP-OT1 corrosion resistant steel for bottom plates and JFE-SIP-OT2 corrosion resistant steel for upper decks have received approval from the Nippon Kaiji Kyokai (ClassNK) and American Bureau of Shipping (ABS) ship classification societies, *etc.* [29], and it is thought that application of these products can contribute to improving the safety of ships.

3.4 Steel Plates for Energy Applications

As a result of increased world energy demand accompanying the development of the emerging economies, even more active construction of offshore structures for marine oil field and gas field development is expected in the future. The regions where new resource development is carried out are continuing to expand into arctic regions and deep waters, and increasingly strict requirements are applied to the plate thickness and mechanical properties, namely, strength and low temperature toughness, of steel products for these applications.

In arctic regions, strict requirements are placed on the low temperature toughness of plates which are to be used in drilling rigs and platforms. In addition to Grade E steel (−40 °C specification) and Grade F steel (−60 °C specification), which are high tensile strength steels in ship classification standards, YP500 MPa class

Table 5 Available strength and thickness of steels for offshore structures

YS Class (MPa)	Charpy temp. (°C)	CTOD test temp. (°C)	Thickness (mm)
355	−40	−10	≦101.6
	−60	−40	≦76.2
420	−40	−10	≦101.6
	−60	−40	≦76.2
500	−40	−10	≦75
	−40	—	≦150
	−60	—	≦150
550	−40	—	≦108
	−60	—	≦63.5
620	−40	—	≦180
690	−40	—	≦210
	−60	—	≦210

heavy steel plates conforming to the NORSOK and EN standards are also used, and fracture toughness based on CTOD (crack tip opening displacement), which is one stringent fracture mechanics parameter, is required in welded joints of these plates.

JFE Steel realized practical application of plates that amply satisfy these property requirements by combining advanced material design and steelmaking technology using microalloying technology, and state-of-the-art controlled rolling technology and controlled cooling technology utilizing the *Super*-OLAC on-line accelerated cooling device. In addition to satisfying a low P_{CM} (weld crack sensitivity composition) design with excellent weldability and base material properties in heavy thickness materials, the toughness and CTOD characteristics of welded joints are also improved by microstructure refinement utilizing Ca oxide inclusions [33, 34].

Ultra-low temperature toughness specification ultra-heavy plates with yield strength of 690 MPa class are used in the rack and chord materials of jack-up rigs. JFE Steel established a manufacturing technology for high quality plates of this type by an original manufacturing process which supports heavy thickness materials for ultra-heavy plates with strict QT (quench and temper) heat treatment specifications, and has an extensive production record for these products. **Table 5** shows an example of the steel plates developed by JFE Steel for offshore structures.

3.5 Large Diameter Steel Pipes and Plates for Large Diameter Steel Pipes

Accompanying the development of marine oil fields and gas fields, use of large diameter pipes has also extended into sea areas with deeper water depths and regions with severe sour environments, and stricter

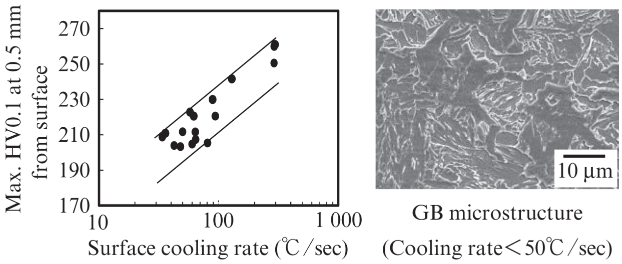

Fig. 10 Relationship between surface cooling rate and maximum surface hardness and microstructure in grade X65 steel plate

requirements are now applied to the specifications of large diameter steel pipes used in pipelines [35].

Regarding sour resistance, because pipelines are being planned in severe sour environments with higher concentrations of hydrogen sulfide (H_2S), large diameter pipes and plates for large diameter pipes with more uniform control of surface hardness are demanded. At JFE Steel, introduction of the *Super*-OLAC-A made it possible to control surface hardness stably by forming a microstructure consisting mainly of soft granular bainite (GB) at the surface of steel plates, utilizing the higher cooling uniformity and highly accurate cooling rate control of this TMCP device [36] (**Fig. 10**).

With increased energy demand in India, Central Asia and Africa, projects in which pipelines are laid in deep waters with depths exceeding 2 000 m have become realistic. The locations of these projects, which are intended to shorten the transportation distance to consuming regions, include the Mediterranean Sea and the Black Sea. Heavy wall thickness pipes are increasingly applied in pipelines laid in deep water to prevent collapse due to the water pressure.

By installing the NEO Press™ high productivity press bending device at West Japan Works (Fukuyama), JFE Steel established a high productivity production process for heavy wall thickness and high strength steel pipes using steel plates for heavy wall, large diameter pipes in which the microstructure is controlled uniformly by applying the optimum TMCP technology utilizing the *Super*-OLAC-A accelerated cooling device and controlled rolling [10].

Table 6 shows an example of the mechanical properties of trial-manufactured grade X65 linepipe. The fraction of shear area (SA) in a drop weight tear test (DWTT) at −10 °C is 100 %, and the steel shows compressive strength exceeding the specified minimum yield strength (SMYS) in the as-formed condition and after aging treatment at 230 °C for 5 min. The collapse pressure calculated by the equation in the DNV-OS-F101 standard [37] is also shown in the table, and confirmed that the steel has excellent collapse performance.

Table 6 Mechanical properties of grade X65 linepipe

YS (MPa)	TS (MPa)	EL (%)	YR (%)	SA at −10°C (%)
507	594	64	85	100

0.5% Comp. YS (MPa)		Ovality (%)	Collapse pressure (MPa)
As formed	After heated		
452	486	0.2	44.2

DWTT: Drop weight tear test

4. Conclusion

This paper introduced the basic technologies related to the *Super*-OLAC, *Super*-OLAC-A and HOP, which are state-of-the-art facilities related to the thermo-mechanical control process (TMCP) at JFE Steel. Moreover the *Super*-CR enables high productivity in controlled rolling and new mechanical property control when used in combination with the *Super*-OLAC, and the NEO Press, which makes it possible to produce heavy wall thickness steel pipes with high productivity. The paper also presents an overview of JFE Steel's high performance and high strength steel plates commercialized by using these facilities, which are the most advanced in the world, in combination with steelmaking technology and metallurgical phenomena.

In the future, JFE Steel will continue to develop TMCP technologies which organically link process development and metallurgical principles and achieve an even higher level of *monodzukuri* technology in order to respond to the needs of customers, and will strongly promote the development of new steel plate products which contribute to society.

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