Technical Review

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Progress in Pipe and Tubes Technology and Its Future Prospects

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Abstract

Nippon Steel & Sumitomo Metal Corporation (NSSMC) has been promoting research and development on pipe & tubes, combining high level technologies which have been cultivated in each company, Nippon Steel Corporation and Sumitomo Metals Industries Ltd. This paper introduces the progress in pipe & tubes technology and its future prospect for each products.

1. Introduction

Nippon Steel & Sumitomo Metal Corporation was established as a result of the merger of Nippon Steel Corporation and Sumitomo Metal Industries Co. Ltd. in October 2012. On the basis of the advanced technologies owned by both the companies, the new company is complementing their strengths and integrating them to develop a variety of new technologies. This paper outlines the technical development of the company's pipe and tube products and their future prospect.

2. OCTG (Oil Country Tubular Goods)

2.1 Overview

The energy demand of the world is growing and the importance of petroleum and natural gas will increase as the mainstay energy sources. In an effort to extend the limit of recoverability, oil companies continue the challenge to drill new oil and gas wells to greater soil depths, in deeper seas, and in severe corrosive environments, which have been difficult methods to develop to date.

Accordingly, the technical requirements for OCTG pipes have diversified and some of them even require ultimate performance of the current manufacturing technology. As soil or water depth increases, the temperature and pressure rises at the well drilling end, which requires the combination of thick-wall pipes made of high-strength steel and coupling joints of high sealing performance to withstand the severe and combined loads of tension, compression, internal pressure, and external pressure. In addition, when highly corrosive agents have to be taken into consideration, it becomes necessary to develop a new high-strength material that can resist both weight loss and cracking due to corrosion.

On the other hand, nonconventional energy sources such as shale oil and gas have become commercially recoverable thanks to the technical development of horizontal well drilling and hydraulic fracturing. As a result, they have swiftly become one of the major energy sources in USA. The requirements of the OCTG pipes are primarily for drilling numerous long horizontal wells economically and in a short period of time, although in comparatively shallower depths.

Another issue currently recognized is environmental protection measures taken during well drilling. To prevent leakage from coupling joints and their galling, a high-performance lubricant called the API dope is used when tightening them. Because the dope contains heavy metal elements to secure good lubricating and sealing properties, its use causes sea and soil pollution. In recent years, a pipe coupling method that does not require the API dope is needed in the North Sea, Siberia, Caspian Sea, and other regions.

2.2 Seamless pipes for OCTG

Seamless pipes for OCTG are produced at Wakayama Works (60.3 to 425.4 mm in outer diameter) and Amagasaki Works (60.3 to 339.7 mm in outer diameter). The pipes manufactured at Wakayama Works are made of carbon steel and steel containing up to 13% Cr. Those manufactured at Amagasaki Works are made of stainless steel (high-Ni alloy steel and dual-phase stainless steel) strengthened through cold working.

Nippon Steel & Sumitomo Metal's lineup of seamless pipes for OCTG for sour-resistant, high-strength carbon steels is as follows:

(1) Pipes for extreme sour services resistant to 1 atm. H_2S or higher are available as the SM-XS series, which comprises SM-80XS, SM-90XS, SM-95XS, and SM-110XS. Pipes of this series having a high collapse resistance, called the SM-TXS series, are available as options.

(2) Pipes for enhanced mild sour services resistant to 0.1 atm. H_2S are available as the SM-ES series, which comprises SM-110ES and SM-125ES. Pipes of this series having a high collapse resistance, called the SM-TES series, are also available as options.

(3) Pipes for mild sour services resistant to 0.03 atm. H_2S are

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called SM-125S.

Pipes of these grades are selected according to the environmental conditions of the well. Pipes having thicker-than-normal walls and non-standard diameters are also developed to meet customers' request.

High-Ni alloy stainless steel pipes such as SM2535 (25%Cr-35%Ni-3%Mo) and SM2550 (25%Cr-50%Ni-6%Mo) are available for wells in extremely corrosive environments having high CO_2 and H_2S. These products, suitable for use at high temperatures, under high pressures, and in highly corrosive conditions, resulted from the technical development of steels resistant to high-temperature sour environments containing free sulfur. Products of enhanced strength for use in greater depths and the pipe manufacturing methods suitable for large-diameter (9-5/8 in. or so) OCTG pipes of high-Ni stainless steels for efficient oil and gas production in increased depths have been developed. The company was twice awarded the Okochi Memorial Prize for the developments in this specific field; first, for the development of high-strength, corrosion-resistant OCTG pipes of Ni alloys in 1993; second, for the development of high-alloy OCTG pipes that enabled significant production increase of natural gas and their manufacturing method in 2013.

Whenever a new grade of OCTG pipes is developed, new and suitable coupling joints along with resistance to increasingly severer conditions have to be developed. As an upgraded version of the VAM® TOP joints for use under combined loads of tension compression, internal pressure, and external pressure, Nippon Steel & Sumitomo Metal has developed VAM® 21 anti-leakage joints with improved sealing and running performance. Their size lineup is being expanded. Further, in response to diversifying customer requirements, other joints of higher performance, smaller sizes, and higher torque have been developed. In response to the worldwide requirement for dope-free joints, VAM® CLEANWELL and VAM® CLEANWELL-DRY have been developed through joint association with Vallourec, France.

2.3 ERW pipes for OCTG

Nippon Steel & Sumitomo Metal manufactures OCTG pipes via electric resistance welding (ERW) at Nagoya Works (114.3 to 406.4 mm in outer diameter) and Hikari Pipe & Tube Division (318.5 to 609.6 mm in outer diameter) for wider applications ranging from production casing to conductor casing.

The ERW OCTG pipes of the company are characterized by high strength and toughness without the requirement of heat treatment for tempering; this is due to the high strength of the material hot bands produced with sophisticated melting technology, through the thermo-mechanical control process (TMCP), reliable pipe forming technology based on unique forming methods, welding control through automatic heat input control, and welding monitoring. The OCTG pipes of small to intermediate diameter of Nagoya Works are characterized by excellent dimensional accuracy, drift properties, and high collapse strength exceeding those stipulated in the API standards; thanks to the high material strength due to the TMCP in hot rolling. Taking advantage of these characteristics, the company has supplied the NT-HE series pipes (widely known as the T.U.F. pipes) having a specific minimum yield strength (SMYS) of 95 ksi or less.

In addition, as the exploration of shale gas and oil expanded in USA over the last few years, high-strength casing pipes of higher collapse strength were required. In response, the company has developed high-collapse-strength casing pipes called NT-110HE having an SMYS of 110 ksi, and launched the product to the market. For this market sector, the company also developed material pipes with expandable tubular casing using a new low-cost well drilling method, and is supplying the pipes for use at low to intermediate expanding ratios. In the meantime, the company will focus on developing next-generation products suitable for use at high expanding ratios and having high corrosion resistance.

Hikari Pipe & Tube Division has supplied casing pipes 406.4 mm or more in outer diameter, which is a size range difficult to produce by seamless rolling. The Division expanded the supply of the product having an SMYS of 80 ksi or less. In consideration of the latest trend of well drilling to greater depths and under increasingly corrosive conditions combined with the consequent demand for higher strength and collapse resistance of well pipes, the ERW line of Hikari was revamped in early 2012 to increase its process capacity. The revamped line is expected to be instrumental in product development to satisfactorily adhere to the customers' increasingly complicated requirements.

2.4 Key points in future technical development

Greater importance will be placed to the advancement in well drilling technology to expand the recoverability of oil and gas resources in order to secure the energy requirements of the future generation. Accordingly, the technical requirements for well pipes will diversify, tend to be increasingly demanding, and integrated with each other. There will be no end to the demand for higher economy, safety, and reliability. Nippon Steel & Sumitomo Metal has supplied a wide variety of high-end seamless and ERW pipes for oil and gas wells. New products of higher performance have to be developed to meet the changing requirements.

3. Linepipes

3.1 Overview

The production sites of petroleum, natural gas, and other energy resources have shifted to regions of severer conditions. Many wells have been drilled over the last few years in the North Sea, Siberia, Canada, Sakhalin, and other cold regions as well as in deep water such as the Mediterranean Sea, the Black Sea, the Gulf of Mexico, and the Atlantic Ocean offshore Brazil. There are examples of many other kinds. Long-distance, high-pressure submarine pipeline projects are promoted at the North Sea, Baltic Sea, and on the northwest continental shelf of Australia; coal bed gas is being developed in east Australia; oil sand is excavated in Canada and other countries; and increasing amounts of shale gas and oil are being developed in USA. While the demand for natural gas increases in consideration of the conservation of the global environment, higher strength is required for the linepipes for the transport of natural gas to reduce the material weight and increase the operating pressure of the pipelines for economic efficiency.

The properties required for linepipes tend to be more demanding and diversified as the development sites of energy resources shift to regions of increasingly severer conditions. Such requirements can be classified as follows: (1) increased wall thickness and higher strength; (2) higher toughness; (3) reduction of the carbon equivalent (Ceq) to improve the weldability (girth welding) at laying sites; (4) enhanced corrosion resistance; and (5) better deforming properties for discontinuous permafrost or seismic faults. These properties are usually required in combination with each other in accordance with the environmental condition of the construction site.

3.2 UOE pipes for linepipes

Large-diameter pipes (457.2 to 1 524 mm in outer diameter) mainly for energy transportation use are manufactured at Kashima

Works and Kimitsu Works. The total accumulated production of the pipes of the two works since the commissioning of the facilities exceeds 26 million tons. The products are serving in various countries of the world as the linepipes for natural gas, petroleum, and other energy sources. Both these works command the world's most advanced technologies in the integrated production processes comprising of steelmaking, plate rolling, and pipe forming to product inspection. Typical examples of such technologies include the following: high-purity steel melting, minimization of center segregation of continuously cast slabs; plate rolling through TMCP or controlled rolling combined with accelerated cooling, known as dynamic accelerated cooling-n (DAC-n) at Kashima and the continuous on-line control process-μ (CLC-μ) at Kimitsu; high-strength and high-toughness welding consumables; high-precision pressing and expanding processes suitably tuned for forming high-strength, heavy-thickness plates into linepipes; the latest non-destructive inspection facilities including digital X-ray inspection equipment and ultrasonic inspection equipment with multi-channel probes and/or phased-array probes; and automatic size measurement. In addition, Nippon Steel & Sumitomo Metal is unique in the respect that it owns the capability of assessing the safety of pipelines. The company has developed a variety of safety simulation programs and frequently conducts burst tests using actual pipes as well.

The metallurgical technologies employed for the UOE linepipe production include the following: optimum steel chemistry to make linepipes resistant to sour gas and excellent in weldability of high-strength joints; process metallurgy (or TMCP) making use of steel chemistry; grain size refinement of weld joints by minute addition of Ti to obtain high toughness of heat-affected zones (HAZ); and oxide metallurgy (using TiO, MgO, etc.). In addition, the company has developed simulation programs based on FEM, which proved effective at enhancing the manufacturing conditions of thick-wall, high-strength, high-deformability linepipes, and further, proposing the pipeline laying and operating practice to customers.

These technologies have proved instrumental in manufacturing and marketing linepipes for sour gas use; for ultra-cold regions, thick-wall line pipes for deep water use, high-strength linepipes, high-deformability linepipes, high-HAZ-toughness linepipes, and so forth.

Linepipes for sour gas use up to the X70 grade by the American Petroleum Institute (API) standard system have been produced and supplied in large quantities. Conventionally, the grade of linepipes for this application was mostly X65 or lower. However, in consideration of customers' requests for lighter pipe weight, reduced costs of site welding, etc., Nippon Steel & Sumitomo Metal brought X70 high-strength, sour-gas-resistant linepipes into commercial reality.

In Alaska, Canada, Russia, and other arctic regions, the temperature often falls to 40°C to 60°C below zero. Nippon Steel & Sumitomo Metal supplies linepipes for such ultra-cold regions for pipelines and gas and oil refineries in these areas. Sour-gas-resistant linepipes for use at around −46°C capable of withstanding adiabatic compression are used for the slag catchers of gas refineries where sour gas is processed.

Thick-wall linepipes for deep water use have been supplied for offshore pipeline projects at the bottoms of the Gulf of Mexico, the Mediterranean Sea, the Black Sea, etc. at depths of 1 500–2 200 m. Their excellent collapse resistance, low-temperature toughness, and dimensional accuracy are highly regarded.

The number of pipelines that use high-strength pipes has increased rapidly over the last few years in view of higher operating pressures, lower costs of the pipes and laying, etc. X80 linepipes have been laid already in many countries including Japan, Canada, China, Czech, Germany, Russia, UK, and USA. The project in China is the West–East Gas Pipeline II, and that in Russia is the gas field development in the Yamal Peninsula. X80 pipes were selected for high-pressure operation over long distances. Moreover, X100 pipes have been supplied to TransCanada PipeLines Limited in two batches for verification tests and commercial use. Nippon Steel & Sumitomo Metal conducted a joint study on the technical viability of laying X120 pipes with Exxon Mobil Corporation, USA, and successfully completed test laying of these pipes in Alberta, Canada, in cooperation with TransCanada PipeLines Limited.

Besides the abovementioned accomplishments, the company has been accredited by the API and the ISO for producing up to X120 linepipes.

For pipelines crossing areas of unstable permafrost or seismic faults, Nippon Steel & Sumitomo Metal has developed highly deformable linepipes capable of withstanding the strain due to deformation of the ground. The steel has a fine, multi-phase microstructure and demonstrates high strength, flexible deformability, and high toughness at low temperatures. Deformable linepipes have been already supplied for projects in Japan, Canada, China, Russia, and other countries.

3.3 Seamless pipes for linepipes

Nippon Steel & Sumitomo Metal manufactures seamless pipes for energy pipeline use at Wakayama Works (15.9 to 425.4 mm in outer diameter), Amagasaki Works (60.3 to 244.5 mm), and Tokyo Works (33.4 to 168.3 mm).

Seamless pipes are used for pipe lines under tough conditions where high performance and reliability are essential such as offshore pipelines, those in cold regions, and those for corrosive oil or gas containing H_2S, CO_2, etc. The strategy of the company in this market sector is to focus on high-end products of high added value in response to the trend of market requirements. The emphasis is placed, therefore, on further sharpening the technical edge.

Many pipelines were recently laid at depths of 300–3 000 m under the sea. As a result, the requirement for high-strength, high-toughness, and thick-wall seamless pipes is becoming increasingly demanding. In addition, to reduce pipe laying costs, coiled pipes applicable to the reel-laying method and improved dimensional accuracy for better weldability of girth joints have been requested. The company has met these requirements satisfactorily thanks to its highest level of technical expertise in the world.

Considering the request for higher toughness required for heavy thickness seamless linepipes, especially those for Northern Europe, Russia, Alaska, Canada, and other cold regions, newer pipe products to meet such demand are being developed.

Nippon Steel & Sumitomo Metal has supplied sour-resistant X65 seamless pipes in quantities for pipelines in the Middle East and the Caspian regions where the H_2S contents in oil and gas are high; the high quality of the product has been greatly relied upon. The company has been promoting the application of seamless pipes of super-13Cr steel and duplex steel to pipeline projects in the corrosive environments containing high H_2S, low CO_2, etc. in the North Sea, Oceania, and South East Asia in close communication with the customers. SM65-2505 (DP25U) has been developed as a new pipeline material of good weldability and high cost performance.

The high-strength seamless X90 and X100 linepipes that the company developed have been included in the API standard system.

3.4 ERW pipes for linepipes

ERW pipes for energy pipelines are produced through the 16 in.

mill of Nagoya Works and the 24 in. mill of Hikari Pipe & Tube Division by the high-frequency induction heating method. These pipe forming lines have since long supplied the products for pipelines offshore in very cold regions and for transporting sour gas. Recently, the company has developed and introduced to these lines a new pipe production method called the "Flexible Forming eXcellent (FFX)," wherein the welding process is optimally controlled through continuous monitoring using cameras.

ERW pipes are manufactured using top-quality, hot-rolled steel strips produced under integrated quality control. Thus, they are cost efficient owing to the high quality of the material and the high productivity of ERW lines. Initially, ERW linepipes used to have strength equivalent to the linepipes of grades up to X65 and wall thickness of 16 mm or less, but the new manufacturing process is now capable of covering the size ranges and grades of the UOE and seamless rolling processes. Accordingly, the market requirements for ERW linepipes have shifted to larger wall thickness, higher strength, and toughness. As the reel-laying method came to be employed for offshore pipelines, the latest requirements focus increasingly on high dimensional accuracy, homogeneous material quality, narrow range of strength distribution, and low yield ratio (yield strength (YS) / tensile strength (TS)); Nippon Steel & Sumitomo Metal started supplying pipe products that meet these requirements.

3.5 Key issues in future technical development

Nippon Steel & Sumitomo Metal manufactures and supplies high-grade UOE, seamless, and ERW linepipes. In view of the market trend that requires a wider variety of linepipes combining various functionalities at higher levels, the company has to focus on developing not only linepipes alone but also their application methods for enhancing the economic performance, safety, and reliability of pipeline systems.

4. Boiler Pipe and Tubes

4.1 Overview

Japan was one of the world first countries to shift the main fuel for thermal power generation from petroleum to coal, which is more economical and was stably supplied in the 1980s. In these circumstances, Nippon Steel & Sumitomo Metal started, as the first runner in the world, the development projects for new boiler tubes for ultra-supercritical pressure boilers (USC boilers) that would operate at higher steam temperatures and pressures than before. The new grade pipes and tubes thus developed have been used for USC boilers in many countries, significantly contributing to the reduction of CO_2 emission and conservation of global environment (The company was awarded with the Okochi Memorial Special Production Prize and the Chairman's Prize of the Japan Institute of Invention and Innovation). Some of the company's unique boiler tube products are presented below.

4.2 Stainless steel tubes for boilers as global de-facto standard

TP347HFG tube (18Cr-12Ni-Nb) that Nippon Steel & Sumitomo Metal has developed proved to have both high strength and excellent resistance to steam oxidation achieved by the optimum alloy chemistry and the fine-grain microstructure obtained through the developed thermo-mechanical treatment. TP347HFG tube is designated in the ASME standard as a permanent grade as the first of the developed boiler tubes since the 1970s. Then, using economical copper as a strengthening element, the company has developed SUPER304H® (18Cr-9Ni-3Cu-Nb-N) tube having a strength 1.5 times that of conventional TP347H tube. SUPER304H tube with a fine-grain structure as well as TP347HFG, has been used for USC boilers all over the world, and is designated in the ASME standard as a permanent grade in 2014.

Steel tubes used for a 600°C steam and in a severe corrosive environment significantly causes hot corrosion because of impurities in coal. HR3C steel tubes (25Cr-20Ni-Nb-N) that Nippon Steel & Sumitomo Metal developed are another world standard boiler material for parts exposed to highly corrosive environments, and have already been designated as a permanent grade in the ASME standard.

4.3 Global standard 9Cr steel pipes with high strength, large diameter, and thick walls for USC boilers

Steel pipes with roughly 350–850 mm in outer diameter and 25–130 mm in wall thickness are used for the main steam pipes and high-temperature reheating pipes of boilers. For such large-diameter and thick-wall pipes for USC boilers, however, austenitic stainless steel is inadequate, as it is prone to thermal fatigue because of large thermal expansion. Nippon Steel & Sumitomo Metal has started to develop steel pipes of Gr. 91 steel (9Cr-1Mo-V-Nb), which is 9Cr ferritic steel tube with excellent high-temperature strength, for application as early as in the 1980s. The company has succeeded in commercially applying USC boilers in Japan before similar measures were taken in other countries. Then, the company has originally developed boiler pipes and tubes of NF616 steel (Gr.92: 9Cr-1.6W-V-Nb-B) with higher strength at high temperatures than that of Gr. 91. As a contribution of W and B, the developed NF616 steel exhibits enhanced creep strength at high temperatures; tubes of the steel have been used for USC boilers in many countries as a global standard boiler material.

4.4 Applications to renewable energy facilities and future prospects of advanced ultra-supercritical-pressure boilers

Steel tube resistant to the dew-point corrosion by sulfuric or hydrochloric acid, S-TEN®, has been developed and used in the low-temperature zones of boilers (smoke stacks and auxiliary facilities). In order to improve resistance to stress corrosion cracking (SCC), XA704 (low C-18Cr-9Ni-2W-V-Nb) and NF709 (22Cr-25Ni-1.5Mo-Nb-N) tubes have been developed and used for boiler tubes.

TP347HFG and SUPER304H tubes have been effectively used for LNG-burning, gas, and steam turbine combined-cycle power plants, serving to increase the steam temperature and enhance power generation efficiency.

High hot-corrosion resistance is required for steel materials for boilers burning biomass fuels and other renewable energy sources. TP347HFG tubes having a fine-grain structure and corrosion resistant HR3C and NF709 have been successfully applied to this kind of a boiler. Steel pipes of these grades also earned many track records of application to incineration boilers for municipal wastes.

Advanced-ultra-supercritical-pressure (A-USC) boilers, sometimes known as the next-generation boilers, are expected to operate at a steam temperature of 700°C or higher. This new type of boiler has been developed under public-private initiative projects in Japan, China, Europe, and USA. Nippon Steel & Sumitomo Metal has participated in all such development projects and has been originally developing high-strength Ni-base alloys such as HR6W (25Cr-43Ni-8W-Ti-Nb) and HR35 (30Cr-50Ni-W-Ti-Nb) for future application.

5. Petrochemical Plant and Refinery Pipes and Tubes

5.1 Overview

Steel pipes of all sorts and grades, such as ERW carbon steels, stainless steels, dual-phase stainless steels, and Ni-base alloys are

used for petroleum refineries and petrochemical plants. Nippon Steel & Sumitomo Metal has been actively developing new pipes and tubes in consideration preemptively of shale oil and gas development, offshore explorations of petroleum and gas, stricter regulations on sulfur in gasoline, etc. Typical examples of pipe materials that the company has developed for applications in this field of industry are presented below.

5.2 Ethylene cracking tubes

New ethylene plants using shale gas as the raw material are planned in USA. Nippon Steel & Sumitomo Metal has developed HK4M (25Cr-25Ni-Ti-Al) and the 25Cr-38Ni-Si-2Mo-Ti-Zr (material symbol HPM) alloys for application to ethylene plants. HK4M and HPM tubes, meant to substitute conventional centrifugal cast Ni-base alloy tubes, are characterized by excellent strength and toughness. Because they are manufactured through the hot extrusion process, longer length and smaller diameter can be obtained. The fins on the inner surface, which can be arranged spirally, accelerate the cracking reactions to increase the ethylene production yield.

5.3 Metal dusting corrosion resistance alloy tubes

Recently, there have been many reports about metal dusting corrosion wherein metal materials are turned into powder by highly carbonizing synthetic gas and falling off in flakes. The developed NSSMC™696 alloy tube (30Cr-60Ni-1.5Si-2Cu-2Mo) is a revolutionary material resistant to metal dusting corrosion due to the surface film of Si oxide and the protective effect of Cu. The NSSMC™696 tube has been designated in the ASME and other international standards, and is expected to expand its applications to chemical plants all over the world. For this innovative development, the company received the Technical Development Prize of the Japan Institute of Metals and Materials.

5.4 Seawater-corrosion resistant pipe and tubes for offshore development applications

Steel pipes and tubes used for marine structures must be resistant to corrosion by seawater. Nippon Steel & Sumitomo Metal developed two grades of dual-phase stainless steel, DP3 (25Cr-7Ni-3.3Mo-N) and DP3W (25Cr-7Ni-3.2Mo-2W-N), resistant to chlorides (pitting corrosion resistance) and super-austenitic stainless steel YUS®270 (20Cr-18Ni-6Mo-Cu) as the materials of pipes and tubes for the application. The company accumulated plenty of track records. Recently, the pipes and tubes of high-strength, highly corrosion resistant dual-phase stainless steel with excellent weldability came to be used for the umbilical tubes of offshore drilling rigs. DP3W, which is designated in the NORSOK standard and others applicable to offshore structures, has been used for such applications worldwide.

5.5 Other developed pipes and tubes for chemical plant applications and future prospects

For application to furnace tubes for the desulfurizing facilities of petroleum refineries, Nippon Steel & Sumitomo Metal has developed and commercialized 347AP steel (extra-low C-18Cr-11Ni-0.25Nb) resistant to the corrosion caused by polythionic acid. This steel has earned a great number of application references because it does not require post weld heat treatment. The demand for 347AP pipes is expected to increase further as the demand for economical crude oil of low grades containing much sulfur increases and tighter regulations on exhaust gas quality are enacted in many countries.

In the field of urea production for chemical fertilizers, steel pipes and tubes resistant to the corrosion caused by urea and stress corrosion cracking (SCC) have been looked for. In response, Toyo Engineering Corporation (TEC) and Nippon Steel & Sumitomo Metal have newly developed the dual-phase stainless steel pipe and tube DP28W™ (27.5Cr-7.7Ni-2.2W-Mo-N) for the original plants designed by TEC. DP28W pipes and tubes have been incorporated in the ASME and many other globally accepted standards. Nippon Steel & Sumitomo Metal accumulated many supply references for TEC's urea production process. In appreciation of this, TEC and Nippon Steel & Sumitomo Metal jointly received the Technical Prize of the Japan Welding Society.

Various steel pipes and tubes suitable in terms of different environmental considerations have to be developed in response to the diversification of the feed stock for the chemical industry and the growing general requirement for a cleaner society. Typical examples of such new requirements include promotion of hydrogen stations for fuel cell vehicles and development of coal gasification processes.

6. Nuclear Power Plant Pipe and Tubes

6.1 Overview

Nippon Steel & Sumitomo Metal has been supplying steel pipe and tubes for a nuclear power plant for the first time in 1956. Since then, the company has supplied products for the core steam generating tubes and other pipes for all the 55 nuclear power plants built in Japan. In 1994 and thereafter, the company acquired customers' qualifications for supplying steel materials for nuclear power plants outside Japan. Amagasaki Works has been approved for the manufacture of steam generating tubes for a nuclear application. The company was awarded with the Okochi Memorial Production Prize in appreciation of the capability of technical development, quality control, and long-term quality assurance of the Works, which has earned numerous supply references. Some examples of the pipe and tubes and the technology of the company for nuclear application are presented below.

6.2 Steam generating (SG) tubes and other application pipe and tubes - advanced technology and high quality

SG tubes for pressurized water reactors (PWR) mostly use Ni-base 690 alloys (30Cr-60Ni). The technologies peculiar to the manufacture of SG tubes include melting and refining to minimize impurities, forming metallographic structure resistant to SCC by a special heat treatment, shape control of micro-precipitates, high-pressure drawing to maximize the signal/noise ratio at ultrasonic test, and die-less U bending to minimize surface damage and deformation. Nippon Steel & Sumitomo Metal has originally developed all these technologies, and manufactured and supplied high alloy tubes to earn trust and credence of customers all over the world for the quality of the products.

Besides the SG tubes, the company has supplied a wide variety of stainless steel pipe and tubes for the cores and auxiliary facilities of large nuclear reactors: such include 690 alloy pipes for the nodes for top-mounted instrumentation, high-purity SUS316 and SUS304 pipes of nuclear application grades for recirculating systems, control rod driving systems, piping in and outside the reactor, proper and feed-water heaters, and precision low-fin tubes of SUS410Ti or SUSXM8 having fine spiral fins on the outer surfaces for use for moisture separation heaters.

6.3 Nuclear power plant pipe and tubes applications according to new safety design and prospect of technical development

Next-generation nuclear reactors, e.g., APWR and AP1000, are being planned, based on a new safety design rule. In consideration of this, Nippon Steel & Sumitomo Metal has been developing methods for forming a new type of corrosion protection film to minimize or prevent radiation exposure due to the elution of Ni, the main

component element of SG tubes, and suppress the radiation exposure of Cr from feed-water heating tubes. In order to industrially obtain surface films that prevent the desolution of Ni and Cr, conventional protective films on the tube surfaces are examined at the atomic level to devise a method of controlling the atmosphere of heat treatment. While more compact and safer reactors are eagerly pursued in parallel worldwide, the company intends to help such development activities from the material side.

7. Mechanical Tubes for Automobiles and Construction and Industrial Machinery

The current, major technical issues in the automobile industry are body weight reduction for fuel economy, environmental conservation, and enhancement of collision safety. Regarding steel tubes, sheets, and wire rods, Nippon Steel & Sumitomo Metal has actively responded to these requirements by developing and proposing new products, methods and facilities for their working and forming, and also those for evaluating and analyzing the steel materials and parts.

For the car weight reduction, the company has supplied ERW tubes of the strength of 1 765 N/mm^2 class, the world's highest level, for door impact beams, which also served to improve collision safety. It has been made possible to manufacture ERW tubes having a wall-thickness-to-diameter ratio (t/D) exceeding 30% through adequate use of the stretch reducer (SR). Taking advantage of this, the company intends to propose the replacement of solid bars with tubes, wherever appropriate, to reduce car weight.

What users of steel look for recently is not simply products but proposals wherein products of special shapes are combined with the methods and facilities for forming and processing them into parts. As a response, the hydroforming process, for example, has made it possible to inflate steel tubes three times or more in outer diameter, far beyond what was possible by conventional forming methods. The process is expected to expand its application and simplify manufacturing processes of automobile parts. While hydroforming originally requires expensive press machines, Nippon Steel & Sumitomo Metal has developed compact forming equipment for hydroforming jointly with a leading car manufacturer, which effectively expanded the industrial use of the method. For this, the company was awarded with the Aida Technical Incentive Prize by the Japan Society for Technology of Plasticity in April 2005, and by the Japan Institute of Invention and Innovation with the Invention Prize in May 2007.

By the three-dimensional hot bending and quenching (3DQ) process, developed by the company and industrially applied since 2012, it is possible to apply three-dimensional forming to steel pipes having strength exceeding 1 500 N/mm^2 without using dies. This process is attracting significant attention in the industrial circle as an unprecedented method, and along with the equipment of forming steel tubes capable of fully exploring the material properties, as such, received the Excellence Award in the Industrial Robot Section at the 5th Robot Award sponsored by the Ministry of Economy, Trade and Industry in October 2012.

Making the most of the high-precision rolling technology for high-purity tubes, Nippon Steel & Sumitomo Metal has developed the material for ultra-high-strength (exceeding 1 000 N/mm^2), high-toughness seamless steel tubes for such applications as the tubes for air bags and fuel injectors for diesel engines, which work under very high pressures. The use of the developed product is increasing in and outside Japan.

Demand for lighter and more economical steel tubes is increasing also in the field of construction and industrial machinery. Nippon Steel & Sumitomo Metal has actively responded to the rising demand by developing and supplying new products such as ultra-high-strength (1 000 N/mm^2 class) seamless tubes for crane booms and ERW tubes of high dimensional accuracy for hydraulic cylinder use.

Japanese automobile makers and construction and industrial machinery builders are constructing an increasing number of plants outside the country. Consequently, it became important for Nippon Steel & Sumitomo Metal to secure the supply routes of high-quality steel tubes to those overseas plants. Thus, the company has put new ERW lines into commercial operation in China, Southeast Asia, India, North America, and Mexico to strengthen the support for the customers' overseas production activities.

In consideration of the market demand for increasingly higher product quality, Nippon Steel & Sumitomo Metal is determined to strengthen its development activities for ERW and seamless tubes production processes, products of higher functionality, and their processing and application technologies, and on these bases, propose overall solutions combining steel tubes with sheet, wire-rod, and shape products.

8. Structural Steel Tubes for Civil and Building Construction Work

To achieve higher performance and lower construction and maintenance costs of structures, high strength, corrosion resistance, and high fatigue strength have been required for structural steel tubes for civil and building construction. Nippon Steel & Sumitomo Metal has developed and supplied unique steel tube products and their joining methods to meet these requirements.

High-strength, large-section steel tubes were required for the construction of TOKYO SKYTREE, the 632-m-tall radio-transmission and observation tower. High-strength and highly weldable, UOE, and press bend steel tubes with yield strength of 400, 500, and 630 N/mm^2, respectively were used for the tower structure. For application to this project, Nippon Steel & Sumitomo Metal developed high-strength, large-wall-thickness tubes having dimensional accuracy, high Charpy impact energy value, and good weldability (low weld crack sensitivity) exceeding those specified in JIS G 3475 (carbon steel tubes for building structure). The product received the approval of the Minister of Land, Infrastructure and Transportation.

Small-diameter steel pipes are used in different methods for soil improvement and foundation work for residences and low-height buildings. They are also used for pilings at small land lots in urban areas, tunnel drilling sites, and in similar restricted conditions. For such applications, Nippon Steel & Sumitomo Metal has developed a method for depression of desired shapes on the surface of steel tubes during hot tube forming/rolling processes and commercialized deformed small-diameter tubes having features such as good bond strength with soil cement and grout. These pipes are advantageous in varieties of applications such as columnar soil improvement, revetment reinforcement, tunnel reinforcement, and columns for photovoltaic power generation panels. Their application is expected to expand to various types of anti-seismic and other disaster prevention measures.

A new type of mechanical joint called PILE-FIT® has been developed for quickly joining steel pipe pilings for soil reinforcement of residence buildings. By this method, the joint between the upper and lower pipe piles need not be welded, sound joints are obtained without requiring special skill or tools, the construction time is shortened, and the total cost is reduced.

Nippon Steel & Sumitomo Metal has developed and supplied unique steel tube products of high added values for structural use, effectively responding to customer requirements. The need for measures against natural disasters is expected to increase. In view of this, the company intends to support the society yet further by developing tube products with higher functionality, their joints and accessories, as well as the methods of their field use.

9. Overview of Piping Pipes and Coated Pipes

Steel pipes for piping use are widely varied: small-diameter pipes are used for water supply, drainage, air conditioning, gas supply, etc., for buildings, plant piping, cable protection, and so forth, while medium to large-diameter pipes are used for transporting oil, gas, and water.

Joining methods are important for small-diameter pipes for piping. The joining method using rolled threads and end flanging (or flaring) is attracting attention recently. Because this joint method has been included in the standard specifications for public building construction, it is expected to become a common practice. As Nippon Steel & Sumitomo Metal's pipes formed through the hot and cold ERW processes are widely trusted to withstand the severe deformation of the flaring work, they will be used widely where this joining method is applied.

Galvanized steel pipes used for a wide variety of applications usually contain such ecologically hazardous elements as Pb and Cd in the coating. In consideration of environmental requirements, Nippon Steel & Sumitomo Metal has launched galvanized pipes containing little quantities of those environmentally loading elements for commercial use. The new product has been confirmed to be better in terms of corrosion resistance, workability, and other functionality aspects than conventional ones.

In the field of piping and linepipes, the specifications of external coated pipes were incorporated in the ISO standard system (ISO 21809) in 2007 to 2011 as global standards. Then, in Japan, based on the ISO provisions, polyethylene-coated steel pipes have been included in the JIS system (JIS G 3477). In this situation, the company has developed and commercially launched steel pipes with three-layer polyethylene coating of highly durable powder epoxy primer on the outer surface; the new product is widely used in Japan and abroad. Aiming at a service life of 100 years, the Japan Water Steel Pipe Association and related companies established a coating structure to extend the life of steel pipes for water services wherein the outer surface is coated with plastics and the inner surface with solventless epoxy resin. The specifications of JIS G 3443 (Coated steel pipes for water service) are being reviewed in line with the new coating method. Accordingly, Nippon Steel & Sumitomo Metal's coated pipes for water services are expected to show a big growth.

The piping pipes and coated pipes of the company are used, close to our everyday life, for the infrastructures and buildings, for city water, gas, communication, and power distribution systems. As such, higher reliability, environmental conservation, and disaster preventive performance are required for them. Nippon Steel & Sumitomo Metal will continue serving the society by developing new pipe and tube products with higher functionality and their application methods.

10. Closing

The development of pipe and tube products of Nippon Steel & Sumitomo Metal for each field of application, and the future prospects in those fields have been presented above. As the top manufacturer of steel pipes and tubes, the company will continue developing new pipe and tube products as well as the methods for their better use to flexibly respond to user requirements.

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