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Progress in Pipe and Tube Technology and Its Future Prospect – Application and Manufacturing –

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Abstract

Pipe is applied in various fields of industry and manufactured through processes with wide variation complying with its application expanding. Following market requirement, pipe tends to be supplied as not only a simple material but also a pre-treated product. This paper introduces the activities of Nippon Steel Pipe & Tube Division on various products and technologies satisfying the industry up till now, and clarifies its future prospects.

1. Introduction

The fields in which steel pipes are finding application are expanding every year, and many of those new fields of application are related to energy. As a consequence, the production and sales of pipe products change in terms of quality and quantity depending on changes of energy-related markets. What is required of the products in the markets can be summarized under the following four keywords: (1) cost saving, (2) environmental protection, (3) safety, and (4) friendliness to landscape.

On the manufacturer side, however, the following are required in order to cope with the above market requirements: product design technology to realize high strength, toughness, corrosion resistance and functionality; manufacturing technology to realize high efficiency and enhance product quality; and capability of proposing solutions in consideration of customers' situations. Nippon Steel Corporation has actively and flexibly responded to these requirements exercising its comprehensive technical capabilities covering from the production of material steel sheets/plates to pipe making and processing.

2. Overview by Application

2.1 Steel pipes for automobiles and industrial machinery

Safety and environmental protection have been the major issues in the automobile industry over the years, and this will remain unchanged in the future. In the field of technology related to steel pipes for automobile use, the above issues have been coped with specifically in the forms of improvement of accident safety, increase in material strength, use of hollow materials for weight reduction, energy conservation, extension of service life and noise suppression measures. Nippon Steel has developed new products and technologies to meet these requirements. As an example of such development activities, the company took the lead in developing and commercializing a 160-kgf/mm^2-class (1,570 N/mm^2-class) high-strength electric-resistance-welded (ERW) steel pipe for door impact beams against side collision. In relation to drive systems, in response to requirement for increasing the strength of propeller shafts, the company developed and commercialized a pipe product of an 80-kgf/mm^2 class excellent in dimensional accuracy and resistant to the softening of the heat-affected zones (HAZ) of a welded joint. In relation to the use of hollow materials, Nippon Steel has actively responded to the needs for expanding the production size range of

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thick-wall pipes: for example, the company has supplied, in cooperation with a pipe drawing company, thick-wall seamless pipes to replace solid bars, and commercialized ultra-thick-wall ERW pipes for application to a variety of car components, taking advantage of the stretch-reducing process, which is one of the unique pipe production processes of the company.

With respect to exhaust systems, we have developed a wide variety of stainless steel pipes in consideration of the heat and corrosion resistance and workability that are required for each of the exhaust system components from an exhaust manifold to a tailpipe behind a muffler. Further, in relation to the hydroforming process, which is attracting attention as an advanced working method of steel pipes, Nippon Steel has proposed solutions such as materials having good workability, work analysis by the finite element method, test processing using hydroforming test equipment and performance evaluation of final products. As a result, thanks to high appreciation of customers, the company holds an overwhelmingly large market share of steel pipes for hydroforming work. In addition, through joint work with a leading Japanese automobile manufacturer, Nippon Steel succeeded in developing a new type of hydroforming equipment [1], significantly more compact than conventional types. Thus, Nippon Steel has consolidated its position as the leading player in the field of industry.

Judging from increasing requests of Japanese automobile makers for direct procurement at their overseas plants, wider application of non-ferrous materials such as aluminum alloys, stricter exhaust gas regulations and requirements for enhanced accident safety, the market conditions of steel pipes for automobile use will increase in severity. It is necessary to meet these market requirements by exercising our overall technical capability to develop not only new products and production processes but also new methods of analysis, application and working.

In the field of steel pipes for industrial machinery, the authors supplied tubular products with emphasis placed on high-functionality products in response to customers' requirements for weight and cost reduction. Typical examples of such activities include the expansion of the production range of thick-wall pipes that are used as the material pipes of cylinders, crane booms and the like and the improvement of strength and dimensional accuracy of our products. It is necessary to cope with the needs for the overall cost reduction covering from pipe production to its use by our customers, and thus it is essential to continue to expand the size range of thick-wall pipes and enhance the dimensional accuracy of our products.

2.2 Steel pipes for plant construction and shipbuilding

As a result of the latest decrease in domestic capital investments, Japanese plant builders have come to face tougher competition in domestic and overseas markets against each other and foreign plant builders. In this situation, they have further intensified cost reduction efforts and globalized their material procurement. In the domestic plant market, regulations were revised, and as a result, a longer service life has come to be required of a material in order to enable long and continuous plant operation, and a stricter quality control system of a material manufacturer as a result of the transfer of the responsibility for welding inspection from the government agency to a project owner. On the other hand, in overseas markets, where Japanese plant builders have concentrated efforts to secure more number of orders because of fewer domestic projects, the number of LNG-related plant project orders awarded to them has increased remarkably. In this kind of projects, material suppliers have to conform to severer specifications requiring high toughness at extremely low temperatures, good resistance to sour gas and so forth.

Nippon Steel supplies a wide range of pipe products of corrosion-resistant steels to meet various needs for extending the service life of a plant. While dual-phase stainless steels have been used for piping that is exposed to corrosive environments containing seawater or chloride, Nippon Steel is supplying pipe products of super-austenitic stainless steels, YUS270 [2], which has yet better corrosion resistance and good workability for construction work; this product has been applied in large quantities to food plants, desalination plants and the like. For the piping of overseas LNG-related plant facilities, the company supplies pipes having both the low-temperature toughness of welded joints and the resistance to corrosive gases, which characteristics were hitherto little compatible with each other.

As a result of the closure of Yawata Seamless Pipe Plant in 2001, Nippon Steel became unable to supply medium-diameter seamless (SML) pipes. In order to overcome the handicap, the company has been actively promoting substitution of SML pipes for plant piping use with ERW pipes. It is necessary for us to continue to promote the SML/ERW substitution principally through the efforts to meet various requirements of overseas plant projects and the expansion of the application of ERW pipes to high-pressure gas piping in domestic projects.

In the field of shipbuilding, on the other hand, demands for crude oil and LNG carriers are increasing remarkably owing to the rapid economical growth of China. Among our steel pipe products for crude oil carrier use, Marilloy pipes for oil loading pipe use resistant especially to both wear by oil sludge and seawater corrosion are well accepted by the users. While conventional coated pipes of ordinary carbon steel require repair work after a few years of use, the Marilloy pipes enable maintenance-free use for 10 years; in some cases of actual application, longer maintenance-free periods have been recorded. In the field of pipe products for LNG carriers, Nippon Steel supplies large-diameter welded stainless-steel pipes having good dimensional accuracy for application to pump barrel tubes in particular. As seen in these examples, Nippon Steel has been actively responding to widely diversified needs of steel pipes for shipbuilding.

2.3 Boiler tubes

When we look at the capacity and steam conditions at Japanese thermal power plants from the viewpoints of economical efficiency and protection of the global environment, it was noted that the capacity, temperature and pressure of steam have increased remarkably over the last years in pursuit of better efficiency and economical performance. As a consequence, high strength, corrosion resistance and economical performance have come to be required of steel pipes used for power plants. In response, the authors developed various new materials suitable for applications to different boiler portions.

High strength, high-temperature corrosion resistance and resistance to steam oxidation are required of superheater and reheater tubes, especially at their high-temperature portions. Austenitic stainless steels are used for these applications. Among these, NF709 steel containing 20 to 25% Cr developed by Nippon Steel has the highest level of creep strength. XA704 stainless steel of a 18-8 series composition, which is more economical and has a higher strength than NF709, has properties, such as resistance to intergranular corrosion, equal to or better than those of conventional products for the same application; XA704 has been registered in the Technical Standard as a standard material for Thermal Power Plants and is expected to be registered also in similar international standards [3].

One of the latest trends is to use ERW pipes for boilers of elec-

tricity wholesale aiming at reducing power generation costs. While ERW boiler tubes are superior in dimensional accuracy and economical efficiency, their most significant problem was the reliability of weld quality. Nippon Steel minimized impurity elements in material steel sheets, established automatic welding control system and improved non-destructive inspection technologies to overcome the problem, and as a result, ERW pipes of the company were used in a substantial quantity for a boiler of a private power plant in 1994 as the first case in Japan. Presently, Nippon Steel's ERW pipes are used in place of low-alloy steel seamless pipes up to JIS STBA 24. Further, there are demands for extra-long boiler tubes exceeding 15 m for application to waste heat recovery boilers used in LNG combined power plants, which are becoming popular among private power plants. Nippon Steel is supplying such products.

As a consequence to the diversification of industrial and household wastes, the boilers of waste incineration plants have come to be exposed to highly corrosive gasses. Resistance to high-temperature corrosion (by chlorides and/or sulfates) is required of steel pipes for the heat conduction tubes of this kind of boilers, and pipes of JIS SUS 309, SUS 310, high-Si or high-Ni series steels are selected for this application in consideration of the content ratios of chlorides and sulfates and steam temperature. Nippon Steel offers a wide variety of products for this application; NF709R, among those, is a high-Cr-low-C steel excellent in resistance to grain-boundary corrosion, and has been used for the boilers of many waste incineration plants. In low-temperature portions of flue gas treatment equipment, air pre-heaters and the like, on the other hand, acid dew corrosion is one of the major problems. Furthermore, the content of chlorides in wastes for incineration has increased recently, and as a result, resistance to the hydrochloric-acid dew-point corrosion has come to be required in addition to resistance to the sulfuric-acid dew-point corrosion. Even stainless steel is sometimes corroded in such an environment, but New S-TEN1 (a low-C-Cu-Sb steel) developed by Nippon Steel is an innovative material having resistance to both the types of acid dew corrosion. The material has been included in relevant domestic standards and its shipment has been steadily increasing [4].

2.4 Pipes for structural use

In the field of civil and building construction where structural pipes are used, the requirements for tubular products are widely varied such as suitability for protective coating and use as composite pipes with concrete and/or other materials, anti-seismic performance, weldability, high strength and landscape friendliness. Nippon Steel has responded to these requirements by supplying products of a wide-ranged menu that includes pipes for power transmission towers, railway stringing poles, round-section columns for building construction, ribbed pipe pilings and warp streak steel pile poles. However, large construction projects of power transmission lines and buildings have decreased in Japan, and it is necessary to cultivate new markets for the products. In such a situation, Nippon Steel is offering unique hot-selling products aiming at satisfying market requirements for economical efficiency, safety, environmental friendliness, and so forth.

Among those, tapered steel pipes for street light poles called Nittetsu Poles, which were launched into the market in 1998, are an innovative product [5]. They are characterized by free design of taper curves thanks to a one-of-a-kind hot spinning-forming process of Nippon Steel and U-shaped ribs provided at the base of poles to significantly enhance fatigue resistance. Whereas a tapered steel pipe has been produced conventionally by bending and welding a trapezoidal sheet, by the warm spinning-process it is produced by heating an ordinary steel pipe and then reducing and forming it using NC-controlled forming rolls while having it rotate at a high speed; any desired taper ratio can be obtained by the process. The product has been widely used thanks to its good appearance and resistance to deformation by resonance. The excellent fatigue strength of the new lighting poles with U-shaped ribs provided at the base is highly appreciated, and the poles have been used for the lighting of the motorway system of Metropolitan Expressway Public Corporation (covering Tokyo and surrounding areas) since 2001. The high fatigue strength structure of Nittetsu Poles was recognized to have significantly improved the service life and safety of street lighting and road sign poles, and the product received the Innovative Technique Award of the Japan Society of Civil Engineering in fiscal year 2004. The product is expected to expand its use in the domestic and overseas markets.

Besides the above, Nippon Steel's menu of unique tubular products and related technologies include pipes of a variety of corrosion-resistant steels (weathering steels for coastal environments, plated pipes, etc.) taking advantage of the company's wide ranges of material sheet and plate products, high-strength pipes for piling work methods (such as the ST Micro-Pile method) suitable for work conditions at anti-seismic reinforcing work of foundations of elevated roads and the like where space is limited in terms of area and/or overhead clearance, and pipes with non-welded fins for small-diameter screw piles. What is required of a steel pipe supplier in this market is comprehensive technical capability to enable optimum material selection in consideration not only of the reduction of construction costs through combination of using and working methods such as welding and enhancement of material strength but also the reduction of the total life cycle costs of a structure, taking into account corrosion protection, fatigue resistance and so forth.

2.5 Steel pipes for piping and coating

In consideration of the variety of fluid flowing inside a steel pipe and the outside environment in which the pipe is used, it is necessary for a steel pipe maker to provide pipes and corrosion protection methods suitable for the condition. Nippon Steel has supplied virtually all the tubular products for water and gas services according to the standards of JIS and the Water Steel Pipe Association of Japan such as steel pipes with zinc plating, coating, vinyl chloride lining and polyethylene lining for ordinary piping, pressure service and water service. In this market sector, too, there are strong needs for environmental protection recently. Taking the lead in responding to the trend toward the reduction or elimination of environmentally hazardous materials used for pipe coating, Nippon Steel has been proceeding with measures such as elimination of coal tar, substitution of asphalt with plastics as the lining material for water supply pipes, and elimination of lead from the internal and external coating of city gas pipes.

The demands for vinyl-chloride-lining steel pipes, which were the chief piping material for water supply, is now declining in all the domestic market because of dioxin problems and the increase in the use of plastic pipes, which are superior in the ease of transportation and workability. In this market situation, it is necessary to respond flexibly to market requirements such as recycling of vinyl chloride and development of multi-purpose coated steel pipe products having the advantages of hybrid materials of steel and plastics. The use of coated steel pipes, in contrast, has expanded from conventional cable protection to uses in underground communication cable boxes (c.c. boxes) and the like as a result of development of new applications.

What is important in this market section is to respond to new trends adequately and in a timely manner.

On the other hand, pipe connection techniques are of importance in this market. In this sense, MCCP Easy Treat and MCCP Fix for the c.c. boxes have been well accepted in the market owing to the earthquake resistance of special light-weight couplings and excellent workability (easy connection and adjustment of length and bending) and durability. In addition, Nippon Steel is developing new piping pipe products, such as a pipe for flaring work, specially designed for various coupling methods.

2.6 Linepipes

Exploration of energy resources such as crude oil and natural gas has expanded lately to cold regions such as the North Sea, Siberia, Northern Canada and Sakhalin and deep sea bottoms of the North Sea, Gulf of Mexico, Black Sea, Indian Ocean, etc., and as a result, the natural environment of resource development sites has become severer than it used to be. As natural gas resource development increases in consideration of global environment protection, reduced steel weight and increased operation pressure are required from the viewpoint of the economical efficiency of pipeline systems, and this trend is expected to remain unchanged in the future. As a consequence to the above environmental changes, increasingly sophisticated and diversified properties such as the following have come to be required of linepipes: (1) increased wall thickness and higher strength, (2) higher toughness, (3) lower carbon equivalent (Ceq) for improving weldability (at circumferential welding) at construction sites, (4) corrosion resistance in tougher corrosive environments, and (5) high deformability on the frozen ground or against earthquakes or fault movements. It is usually the case that two or more of the above properties are required in combination depending on the conditions of construction and use.

Nippon Steel has established the integrated production technology of linepipes covering from steelmaking to plate rolling and pipe forming in response to the above requirements. The principal elementary technologies that compose the integrated production technology are the following: high-purity steel production technology; minimum center segregation technology; controlled rolling and thermo-mechanical control processing (TMCP); welding materials of a low-oxygen type for high-toughness welding; automatic heat input control of ERW; on-line heat treatment of ERW seams; and a sophisticated quality assurance system. On the metallurgical side, the integrated production technology is backed mainly by technologies such as the following: steel chemistry of low-C-Nb systems containing other strengthening elements (B, Mo, etc.) in consideration of weldability; process metallurgy (thermo-mechanical control process) on the basis of the steel chemistry; crystal grain refining technology by addition of Ti in a very small amount; improvement of the toughness of heat affected zone (HAZ) of a welded joint by means of oxide metallurgy (using TiO, Mg, etc.); technology for securing the toughness of welded joints of sour-gas-resistant steels; and hardness control of a T-cross portion, where a circumferential joint welded at the construction site and a longitudinal seam welded at the pipe production plant meet at right angles.

These technologies are incorporated in a wide variety of linepipe products such as a high-strength linepipe, high-deformability linepipe, sour service linepipe, thick-wall high-HAZ-toughness linepipe, high-corrosion-resistance linepipe, and low-yield-ratio type ERW linepipe. Among these, especially the high-strength linepipe is one of the new products in which Nippon Steel is the world leader. API X100-class linepipes have been included in the usual product line-up of the company, and high-HAZ-toughness and high-deformability types of these linepipes are made available in accordance with the condition of use. An API X120-class linepipe [6], which has been developed jointly with ExxonMobil, is an epoch-making product having good weldability and high toughness in which Nippon Steel's innovative technologies such as steel chemistry design, chemical composition control, TMCP condition control, plate shape control, optimum pipe forming and new welding materials are crystallized. The first commercial production and actual application of this new product, which significantly contributes to the realization of an economically efficient long-distance pipeline, to a real project will attract attention worldwide.

Another linepipe product (trade name Tough-Ace) [7] having a thick wall, high toughness and high deformability is a unique product to meet current needs and applicable to a wide variety of conditions such as use at a deep sea floor or in a cold region. Its material is a modification of highly appreciated TiO steel with an improvement of HAZ toughness by means of Mg, and in addition, the material has enhanced ductility (large uniform elongation) brought about as a result of a revision of TMCP condition. Regarding ERW linepipes, a lower yield ratio than was conventionally possible has been realized thanks to the new forming method called FFX (standing for Flexible Forming eXcellent) explained later herein, and the products by the method are expected to gain market penetration.

The market is expected to continue requiring high-performance and multifunctional products that are applicable to widely varied conditions of construction and use. With this in mind, what is essential in our future technical development is not to look only at linepipe products alone but spread our activities more comprehensively so as to cover the performance and safety of pipeline systems, standardization on the supply side, development of multipurpose products, etc.

2.7 Oil courtry tubular goods (OCTG)

The sites of energy resource development have expanded into far-off and severe-condition regions, which has made oil developers more eager to reduce development costs. As a consequence, higher strength, better corrosion resistance, enhanced safety including connections have come to be required of OCTG. Nippon Steel has responded to such market needs by supplying a variety of seamless OCTG and accessories such as high-strength sour-gas-resistant pipes, 13%Cr steel pipes, proprietary high-torque gas-tight connections and environment-friendly dope-free connections. The company has also developed related software such as the techniques of material selection in corrosive environments and optimum casing design. At the same time, the company has supplied high-quality ERW OCTG on the basis of the technologies of TMCP, automatic heat input control, on-line heat treatment of welded seams, etc. for applications to large-diameter conductor casings, which cannot be coped with by seamless pipe production methods, and intermediate casing and production casing; such ERW pipes have been effective for reducing procurement costs of well developers.

After the closure of Yawata Seamless Pipe Plant in 2001, Nippon Steel has concentrated its OCTG activities on products with which the advantages of the ERW method are fully enjoyed. Among such products, the ERW OCTG (commonly known as TUF pipe), which has better collapse resistance and higher toughness than similar API standard products, is expected to contribute to reducing oil well development costs further through weight reduction by virtue of its excellent performance. It is necessary in the future to enhance the strength of our current ERW OCTG products yet more and develop pipe products for special casing applications such as high-ductility

casings used for the new well drilling methods now widely attracting attention and special casings of a low-residual-stress type that require less process steps of secondary work.

3. Overview by Manufacturing Process

3.1 UOE pipes

Over the last few years, Nippon Steel has taken improvement measures mainly such as productivity enhancement and introduction of additional inspection equipment for quality assurance in relation to UOE pipes. In the meantime, the development sites of natural gas and other energy resources has expanded into far-off regions and deep sea floors, and more stress has come to be placed on the economical efficiency of pipelines. As a consequence, requirements for reduction of steel weight and high-pressure operation of pipelines have increased. In such a situation, increasingly larger strength and heavier wall thickness are required of UOE pipes, and this trend is considered to remain unchanged for the time being. Ultra-high-strength linepipes are expected to constitute the mainstream product of the UOE pipe market in the near future. In view of the above, it is necessary for us to solve sophisticated and complicated process problems such as clear definition of forming capacity, enhancement of forming accuracy, establishment of high-quality seam welding in relation with the foregoing, and inspection and evaluation methods of pipe quality. In addition, it is indispensable to take integrated measures covering upstream processes: these include stable production of ultra-high-strength steels and improvement of center segregation at the steelmaking process, and intensive TMCP and accurate plate shapes at the plate rolling process. Nippon Steel tackled all these problems, ahead of competitors, on the occasion of the development of the X120 linepipe.

In the past, there were many ups and downs in the demand for linepipes, and for this reason, productivity enhancement of production equipment continues to be an important issue either in a high season or low season. In this respect, what is important is to secure time for large-lot orders through smooth production of small-lot domestic orders for piping and structural applications. For this purpose, we have been taking down-to-earth measures such as evening out of capacity imbalance between individual processes for different product specifications and reduction of setting change and adjustment time of individual facilities.

Since requirements for the enhancement of quality assurance is expected to become more and more demanding in pursuit of high product quality and safety, we are determined to continue to refresh non-destructive inspection facilities and enhance customer services such as supply of production data. Improvement of HAZ toughness of thick-wall and ultra-high-strength materials is a very challenging task, and we have tackled the problem through material-side approach by means of oxide metallurgy. An approach from the welding technology and process side will also be required.

3.2 Spiral pipes

Spiral pipes have been used mainly in the form of pipe piles or steel pipe sheet piles, especially for civil construction. However, in consideration of the latest decrease of civil construction projects in the public sector, it is necessary to strengthen efforts to penetrate into the market of building foundation pilings. Development of high-added-value products and improvement of cost competitiveness are the keys to this market sector. Nippon Steel has promoted process mechanization and laborsaving of spiral pipe manufacturing processes such as increase in seam welding speed by a new welding process that combines ERW with submerged arc welding (SAW) and automatic welding of steel pipe sheet piles. Attention was paid to the material flow in secondary work processes, which are more complicated than the pipe forming process, and shortening of work periods and reduction of handling costs have been achieved through improvement of material handling and introduction of production control systems. As examples of new high-added-value products, ribbed pipe piles excellent in anti-seismic performance and screw piles excellent in workability in terms of soil removal and noise suppression have been developed and commercialized.

Cost competitiveness is a permanent challenge. Efficient manufacturing systems for small-lot orders of diversified products and short delivery time will be required more strongly. In this relation, reduction of setting change time and on-line processing of secondary work, either of which has not been studied as yet, will have to be tackled to further improve productivity. Other challenges include strengthening of fundamental capacities such as capacity increase of high-added-value and thick-wall products for the purpose of increasing the use of steel and coping with private sector demands.

3.3 Medium-diameter ERW pipes

A medium-diameter ERW pipe is used mainly as a linepipe, OCTG or structural member. What is required of an ERW pipe in the linepipe market is high reliability of welded seams comparable to that of seamless and UOE pipes. The performance of Nippon Steel's medium-diameter ERW pipes, backed by the proprietary technologies of automatic heat input control and heat treatment of welded seams and a substantial non-destructive inspection system, was so highly appreciated that they began to be used for offshore pipelines recently. Further, in the field of OCTG, the company succeeded in developing and commercializing a no-heat-treatment type high-strength ERW OCTG having high collapse resistance through the combination of TMCP and forming technologies and using a high-strength ERW pipe of a 690-MPa class or higher.

In order to better respond to the market requirements for products of wider variety and higher quality, a new pipe forming technology [8] was introduced in 2003. The new pipe forming technology is epoch-making in that it enables production of pipes having a maximum diameter of 24 in. by ERW, while the maximum diameter by the ERW method was, conventionally, 16 in. As a result of the introduction of the new forming technology, the basic quality items of product pipes such as yield ratio and residual strain have been improved. Lower yield ratios have been requested in the linepipe market recently, and thus the ERW pipes by the new technology are expected to penetrate the market.

While improvement of productivity has been a difficult problem to solve in the production of small-lot orders of structural pipe products, the new forming method is effective also as a means of size-free production, leading to the shortening of setting change time; thus it is expected to bring about a significant productivity improvement.

A challenge taken up by the authors, in the field of medium-diameter ERW pipes, is to respond to increasingly diversified and strict product specifications and open up new market sectors. In this relation, further enhancement of the reliability of welded seams is essential. For this end, what is required is to build up the technologies for more precisely quantified heat input control, monitoring and atmosphere control of seam welding, enhance our quality assurance system through consolidation of non-destructive inspection processes, and establish production technologies of low-and high-alloy steel pipes for newly developed market sectors.

3.4 Small-diameter ERW pipes

The Nippon Steel group operates small-diameter ERW pipe mills at Kimitsu and Nagoya Works (the equipment at Nagoya is operated by Nittetsu Steel Pipe Co., Ltd. under an OEM contract), and each of the plants is responsible for different products according to their respective equipment characteristics. The 4-in. ERW line of Kimitsu specializes in ultra-thick-wall, low-alloy and high-carbon steel pipes, and its products are high-grade pipes that take the advantages of cold pipe forming such as boiler tubes, high-strength pipes for automobile use and low-alloy steel pipes. The pipe mill of Nagoya, on the other hand, is responsible mainly for automobile pipes with or without secondary working, and characteristic products such as high-strength propeller shafts and door impact beams are manufactured using the pipes from the mill.

The products of small-diameter ERW pipe mills are quite diversified in terms of size, strength, etc., and as a consequence, the size of their orders is usually small. For this reason, pipe forming lines are subject to frequent roll changes and adjustments for product size changes. In addition, conditioning lines have to cope with different product specifications of many customers. In such a situation, the most important task is to enhance productivity by measures such as reduction of preparation and roll changing time and increase in the ratio of direct shipping after pipe forming through less or no conditioning processes. For this end, improvement measures have been taken, such as the introduction of the high-accuracy pipe forming technology to the Kimitsu ERW line, and that of the flexible forming mill technology to the Nittetsu Steel Pipe ERW line at Nagoya. It is necessary to further improve product quality mainly through the high-accuracy heat input control and atmosphere control of seam welding, and also productivity through streamlining of material flow inside the plants.

From the viewpoints of market cultivation and response to market requirements, on the other hand, it is necessary to establish stable production of high-strength thin-wall pipes and, for the purpose of substituting bar products with ERW pipes, high-strength thick-wall pipes. It is also necessary to propose to customers new products that meet their needs to simplify work steps (reduction of drawing steps, elimination of heat treatment, etc.) on the basis of value analysis methods.

3.5 SR-PIC pipe

The SR-PIC pipe is a unique pipe-in-coil product of Nippon Steel having a length of up to 1,000 m, and is produced through a combined process consisting of an ERW line, a hot stretch reducer (SR) and a garret reel, which is originally used for wire rods. By the ERW + SR process, a mother pipe is formed in a single outer diameter by the ERW process, and it is reduced into different outer diameters by the SR process. For this process, we have established the technologies of constant temperature control to enhance the reliability of welded seams, optimization of edge bending curvature for efficient and high-quality production of a wide size range from ultra-thin-wall to thick-wall pipes and optimum SR reduction. In the coiling process, we have put to commercial application the technology of pipe pre-deformation to maintain the product roundness. As a result, a wide size range of high-quality SR-PIC pipes have been developed and widely used for applications such as automobiles and road deicing water piping.

What is required from now on is to expand the product line-up of high-added-value SR-PIC pipes by improving seam quality yet further through the high-accuracy heat input control and atmosphere control of welding, which are technologies common to small- and medium-diameter ERW pipes, expanding the size range towards the thick-wall side and ultra-thin-wall side taking advantage of this unique process, enhancing the dimensional accuracy of thick-wall products, and further consolidation of our quality assurance system.

3.6 Continuous butt-welded (CW) pipes

A continuous butt-welded pipe mill is a facility specialized in mass production mainly of small-diameter pipes for water and gas supply at high productivity and low costs. However, as a result of the change of market situation of pipes for general piping use as stated earlier, its production has been on a declining trend. In such a situation, it is necessary to further improve cost and quality competitiveness to develop new market sections, and develop multi-functional coated pipe products to respond to the calls for environmental protection. So far, we have taken productivity and quality enhancement measures principally such as introduction of low-temperature butt welding technology, significant improvement of manpower efficiency by process mechanization and flexible manning, in which every operator handles most of the work positions in the plant, enhancement of the quality of as-formed pipes and improvement of direct shipping ratio by minimizing operation and equipment troubles. In the future, it is necessary to improve the direct shipping ratio yet more in the cost aspect, and in the quality aspect, take measures to improve the quality of fitting portions, enhance the quality of zinc plating, which is one of the secondary work processes, and stabilize the production of multi-functional coated pipes.

3.7 Hot extrusion pipes

The hot extrusion process is capable of producing quite a wide variety of sections, either solid or hollow, and pipes of different steel grades through adequate shaping of the opening of a die. The process is more suitable for small-lot production than rolling processes because the cost of an extrusion die is far lower than that of rolling rolls. Presently, our hot extrusion facilities are producing section products of 500 different shapes monthly, and as a result of the expansion of the line-up of complicated shapes through measures such as improvement of die design, the total number of product shapes/sizes is in excess of 5,000. It is necessary to enlarge the sectional area, reduce wall thickness and enhance dimensional accuracy for better coping with diversifying applications. We will expand shape and size ranges of the hot-extrusion products yet more by developing new die shapes and materials and new lubrication techniques.

Most of the pipes produced by the hot extrusion process are stainless steel pipes. The production range has expanded in terms of steel grade and size as a result of improvement of die mandrels and development of new lubricants suitable for extruded materials, and our efforts in the above field were rewarded by the Ohkouchi Commemorative Production Award. The maximum reduction of area has been raised to 99% (for JIS SUS 304) to significantly contribute to expanding the size range of small-diameter and thin-wall products. What is required in the future is to further increase the ratio of hot final products (elimination of cold working) by improvement of dimensional accuracy and surface quality.

3.8 Seamless pipes (small-diameter plug mill)

The seamless pipe mill of Nippon Steel's Tokyo Works is the only plug mill among small-diameter seamless pipe mills of Japan. The layout of the mill equipment is such that the steel material goes through the processes of piercing, rolling, inspection and banding directly and continuously, and thus the mill is excellent for small-lot and short-delivery-time orders. The plant includes also a drawing facility and cold working processes equipped with non-destructive inspection facilities for quality assurance, and thus it is capable of

responding quickly to small-lot production. The plant has produced and supplied unique products such as small-diameter ultra-thick-wall pipes and fitting pipes meeting widely different requirements mainly of domestic customers. It is necessary to improve surface quality and dimensional accuracy, which are common drawbacks of plug mills, and enhance the characteristic capacity of the mill to respond to small-lot and short-delivery-time orders. It is also necessary to relieve the bottleneck in the cold working processes and streamline the material flow in the plant to improve productivity.

4. Closing

The manufacturing methods of pipe and tube products are widely varied, the products are related to a wide variety of industries, and their applications are becoming increasingly diversified. Demands for the products are thus influenced by a change of market trends and environments, however small the change may be. It will become increasingly important for a steel pipe supplier, on the market side, to respond to requirements of stricter specifications and higher functionality of products and to propose solutions in consideration of users' conditions, and on the production technology side, to enhance efficiency and product quality. Nippon Steel's Pipe and Tube Division is determined to strengthen the company's comprehensive technical capability to respond to these requirements flexibly.

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