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Technical Review

Product Development on Market Trends of Stainless Steel and Its Future Prospects

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Abstract

In Japan, since the first commercial operation of the wide width cold-rolling mill in 1958, the production of stainless steel has steadily extended for 50 years. This growth has been brought by the right time development of new stainless steels having higher performance as well as utilizing methods as the appropriate solutions for customer requirements currently reflecting the social requests and the market trend. In this report it is reviewed that the progress of stainless steel and its application corresponding to the trend in typical markets and then it is also surveyed that the future trend of the stainless steel with the social conditions such as "security, relief" "global environments."

1. Introduction

In Japan, production of cold-rolled stainless steel sheet employing large-width strip mills started in 1958. Thanks to earnest efforts to improve product quality and cut production costs, stainless steel has rapidly become widespread since then. In the early 1970s, annual stainless steel production in Japan reached some 1.6 million tons (about a third of global stainless steel output) and Japan took over from the United States as the world's top producer of stainless steel[1]. Since then, stainless steel production has steadily increased on a global basis. By 2007, it was some four million tons in Japan, which had already entered a period of stability in terms of volume in the 1990s. In the same year, global production of stainless steel totaled 28 million tons following a worldwide annual increase of about five percent per annum.

In this article, we review the course of product development that Nippon Steel & Sumikin Stainless Steel Corporation (NSSC) has taken in response to the expansion in stainless steel demand and growth in the stainless steel market. In addition, we consider future product development in the field of stainless steel, which continues to evolve in response to increasingly diverse and sophisticated needs.

2. Growth of Output and Change in Demand Structure[2]

Changes in the stainless steel demand structure and market trends in Japan over the past few years are presented in **Fig. 1** and **Table 1**[3]. In Japan, the development of stainless steel began in earnest with the advent of the large-width strip mill, which dramatically improved the dimensional accuracy, shape and cost of cold-rolled steel sheet, and with the boom in modern housing construction that was triggered by rapid economic growth. In the 1960s and 1970s, various types of stainless steel appliances for home and business use, such as kitchen sinks, powerfully bolstered demand for stainless steel. They paved the way for stainless steel to become a common material used in many daily necessities, as it is today. On the other hand, for some time, the largest demand for stainless steel was for industrial machinery and equipment, including production facilities and various types of plants. In the 1980s, demand for stainless steel expanded noticeably in the fields of construction (mainly building materials), transportation and electrical appliances. Since the 1990s, in response to mounting concern about environmental pollution, demand for stainless steel for transportation equipment, specifically automobile exhaust systems, has been increasing markedly.

Although the demand structure for stainless steel has more or

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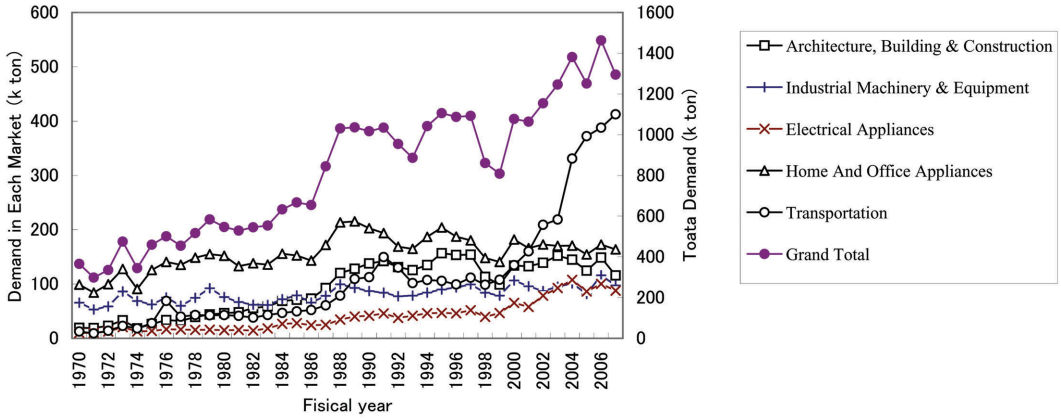

JSSA : Statistical Yearbook of Orders for Stainless Steel Flat Products by Market Classification
Note : Heat resisting steel is included in each demand from 2004 to 2007

Fig. 1 Changes in domestic demand of flat products of stainless steel for typical market classification in Japan

Table 1 Changes in domestic demand of flat products of stainless steel for typical market classification in Japan

Market classification (major category)	1977		1987		1997		2007		2007/1977
	Demand (k ton)	Share (%)	Demand (k ton)	Share (%)	Demand (k ton)	Share (%)	Demand (k ton)	Share (%)	Growth (%)
Architecture, building & construction	32	7	93	11	154	14	116	9	361
Industrial machinery & equipment	60	13	78	9	99	9	97	8	162
Electrical appliances	16	4	25	3	52	5	88	7	539
Home and office appliances	135	30	172	20	180	17	164	13	121
Transportation	(36)	(8)	61	7	112	10	413	32	1,147
Others	175	38	416	49	495	45	418	32	239
Grand total	454	100	844	100	1,092	100	1,295	100	285

JSSA : Statistical Yearbook of Orders for Stainless Steel Flat Products by Market Classification
Note : Heat resisting steel is included in the demand of 2007

less changed according to the prevailing social situation, the demand for stainless steel has continued to increase in individual fields. This is attributable not only to an expansion in applications for stainless steel, which has a number of desirable properties, such as excellent corrosion resistance. It may also be attributable to the strenuous efforts of the individual stainless steel manufacturers to develop new steel grades and new uses to meet ever-changing needs, develop and propose new application and processing techniques, introduce advanced facilities, and improve product quality while cutting production costs through the development of new manufacturing technologies.

Fig. 2 shows the main ferritic and martensitic stainless steel products of NSSC. **Fig. 3** shows the main austenitic and austenitic-ferritic ("dual-phase") stainless steel products of NSSC, with the horizontal axis representing the year of development, and the vertical axis representing the pitting index. In the section that follows, we describe the remarkable achievements of NSSC in the representative fields of demand for stainless steel.

3. Achievements of NSSC in Fields of Demand for Stainless Steel by Use

3.1 Appliances for home and business use

The use of stainless steel began in earnest with items of daily necessity, such as tableware, containers, cutlery, watches, heaters and office equipment. Of these, kitchen sinks represent a typical example. Concrete or tile-covered sinks were first replaced by ones made by press-forming SUS 304 (18Cr-8Ni stainless steel) sheet. In system kitchens, which debuted around the mid-1970s, cabinets made of laminated board were gradually replaced by stainless steel cabinets. Today, almost all kitchen sinks are made entirely of stainless steel. The reason for this is that the superior corrosion resistance, workability and cleanliness of stainless steel have come to be widely accepted. Unlike conventional rectangular sinks, many modern sinks for home use have an irregular opening (so-called deformed sinks) so as to provide extra space in which even large plates and pans can easily be washed.

In response to the evolution of sink design mentioned above, early on NSSC developed and commercialized NSSC® 27A (17Cr-7Ni-2Cu stainless steel) which offers superior press formability and season cracking resistance to SUS 304. For designed sinks, NSSC recently developed NSSC 27AS (17Cr-7Ni-2Cu-LC, N stainless steel), which is softer and easier to form in severe working conditions than NSSC 27A. This stainless steel is widely used today (**Photo 1** (a)).

For commercial kitchen equipment, which needs to be carefully and routinely maintained, ferritic SUS 430 (17Cr) had long been used exclusively. Recently, however, low interstitial ferritic NSSC 430D (17Cr-Ti-LC, N), which features excellent deep-drawability has come to be used for larger, deeper sinks.

The major achievements of NSSC in this field include: the application of NSSC 190 (19Cr-2Mo-Nb, Ti-LC, N) to solar water-heaters which need to have good resistance to crevice corrosion and stress corrosion cracking (SCC) under a hot water environment exceeding

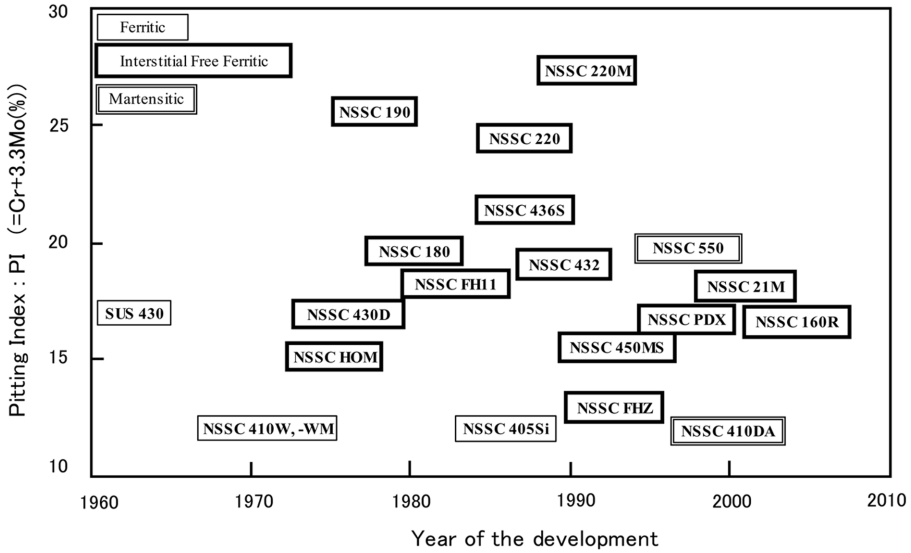

Fig. 2 Representative ferritic and martensitic grades of NSSC® series in the relation between development time and pitting index: PI (= Cr + 3.3Mo (%)) of the each steel

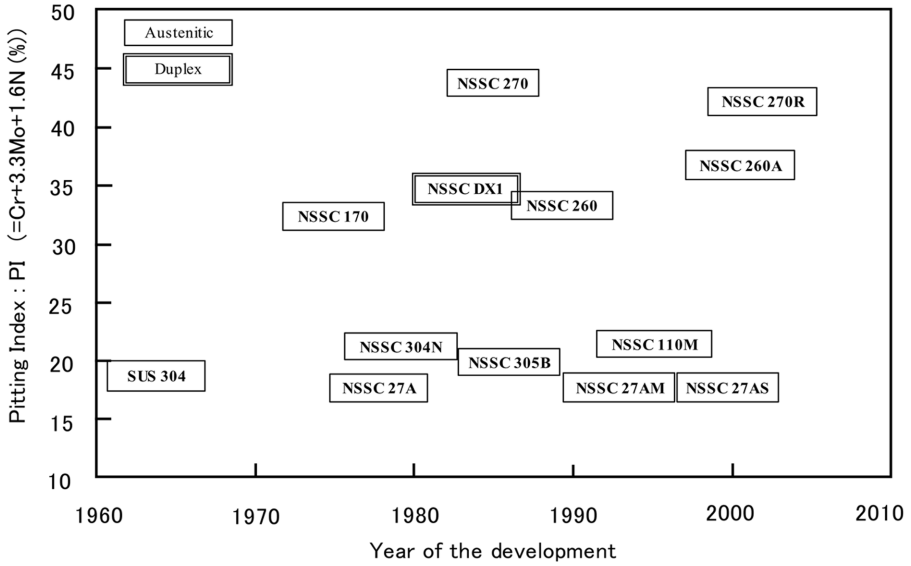

Fig. 3 Representative austenitic and duplex grades of NSSC® series in the relation between development time and pitting index: PI (= Cr + 3.3Mo + 16N (%)) of the each steel

(a) Odd-shaped sink (NSSC 27AS)　　(b) Fasteners and cooking net made of NSSC 160R wire rod

Photo 1 Application example of home utensils and kitchen ware (including professional use)

80℃; the development of heat-resistant ferritic stainless steels—NSSC HOM (14.5Cr-4.5Al-Ti-LC, N), NSSC 405Si (13Cr-2Si) and NSSC FH11 (18Cr-2.5Si-Nb-LC)—for the burners in room heaters, such as stoves; and the development and application of NSSC 160R (17Cr-0.4Cu-Nb-LC) for general-purpose wire rods for machine screws, wire nets, etc. (Photo 1 (b)). For decorative panels applied to bathroom and kitchen walls, NSSC has supplied SUS 430-based precoated and laminated sheets.

3.2 Industrial equipment

In fact, it was the chemical industry that first used stainless steel in earnest. Initially, stainless steel was used in nitric acid and other chemical plants and papermaking machines, etc. More recently, it is also used in food processing equipment and flue-gas desulfurization equipment for air pollution control, etc. Today, large quantities of stainless steel are required for thermal and nuclear power plants, and seawater desalination plants, etc. All these applications utilize the desirable properties of stainless steel, such as its excellent corrosion and heat resistance, outstanding mechanical properties, and good weldability. In this field, various forms of stainless steel—plate, sheet, tube, bar & wire rod—of many different sizes are demanded. Therefore, standard general-purpose steel grades whose properties are well balanced, such as SUS 304 (L) and SUS 316 (L), are widely employed. NSSC has made strenuous efforts to ensure stable supply of stainless steel plates for welded tubes and stainless steel wire rods for welding materials, as well as stainless steel plates, clad plates, sheets and bars & wire rods used for structural members. The stainless steel products of NSSC are also used for those parts of nuclear power plants that demand extremely strict quality control and quality assurance.

It is not uncommon for industrial equipment to be used in special environments, which have become increasingly diverse and rigorous. Accordingly, the equipment is required to have higher durability.

In order to meet such stringent requirements for industrial equipment, NSSC has developed various new stainless steels that have superior corrosion resistance. They include: austenitic stainless steels NSSC 170 (25Cr-13Ni-0.9Mo-0.3N), NSSC 270 (20Cr-18Ni-6Mo-0.7Cu-0.2N-LC), NSSC 260 (20Cr-15Ni-3Mo-1.5Cu-0.2N-LC), NSSC 270R (20Cr-23Ni-6Mo-LC), NSSC 260A (22Cr-16Ni-3.5Mo-2Cu-0.2N-LC); dual-phase stainless steel NSSC DX1 (22Cr-5Ni-3Mo-0.13N-LC); and ferritic stainless steel NSSC 190L (19Cr-2Mo-Nb-V-ULC, N). These stainless steels have many applications. For example, NSSC 170 has long been used for desulfurization, denitrification and firing equipment, etc., and NSSC 260 is employed for the inner linings of stacks in coal-fired thermal power plants, sulfuric acid plants and flue-gas desulfurization equipment, since all are exposed to a highly corrosive atmosphere produced by the alternation of hot, humid gases and sulfuric acid condensation temperatures. For seawater desalination plants and food processing plants, including salt pits and soy-sauce tanks, which are exposed to high concentrations of chlorine ions, the super stainless steel, NSSC 270, is used (**Photo 2**).

Tank of unrefined soy sauce (NSSC 270)

Photo 2 Industrial usage

3.3 Building materials and construction

The use of stainless steel in this field began with the application of SUS 304 and SUS 316 (17Cr-10Ni-2Mo) to sashes, doors, and handrails, etc. With the development of techniques to apply various types of surface finish (polished, colored, clear coatings, etc.) which add to the aesthetic appeal of stainless steel surfaces, stainless steel has been widely accepted as a desirable material for interior and exterior parts.

Japan has an extensive coastline and most of its metropolises are fairly susceptible to damage caused by fine salt particles borne on marine winds. Therefore, the materials used for the roofs and walls of large structures in those areas must have good corrosion resistance. In addition, fabricating any roof which is considerably long and wide requires a material that has a small coefficient of thermal expansion. In order to meet those requirements, our company early on developed NSSC 220 (22Cr-0.8Mo-Nb-LC, N)—a low interstitial ferritic stainless steel. This stainless steel was applied to the roof of the Makuhari Messe International Convention Complex in 1989 (**Photo 3** (a)). That was the first massive roof in the world to incorporate ferritic stainless steel. Since then, low interstitial ferritic stainless steels have been widely used for the exteriors of large structures.

In addition to NSSC 220, the company created NSSC 220M (22Cr-1.6Mo-Nb, Ti-LC, N), which has better corrosion resistance. This stainless steel has been applied to many structures at home and abroad (Photo 3 (b)). On the other hand, in Okinawa and some other areas where saline damage is especially severe, NSSC 270—an austenitic super stainless steel—is utilized effectively (Photo 3 (c)). In order to meet the diverse requirements of roofs and walls, the company also offers aluminum-plated stainless steel products and pre-

(a) Makuhari messe (NSSC 220)

(b) Sapporo dome (NSSC 220M)

(c) Wing of Naha Air Port Building (NSSC 270)

Photo 3 Roofing examples in construction and architecture

coated stainless steel products ("NAR COLOR").

Today, stainless steel is widely recognized not only as a desirable exterior material but also as an exceptionally versatile material. This is largely attributable to the R&D activities that have been conducted in earnest by stainless steel manufacturers, including the development of technology for stable production of stainless steel that meets stringent requirements unique to decorative materials—anti-dazzling matt finish and uniform surface—and the establishment of criteria to select the right stainless steel grade for a specific purpose on the basis of environmental conditions measured in Okinawa and various parts of Honshu[4, 5].

In this field, four austenitic stainless steel grades (SUS 304A, SUS 304N2A, SUS 316A and SCS13AA-CF) were newly included in JIS G 4321: Stainless Steel Materials for Building Construction in June 2000. Welded H-beams and other structural members made from NSSC stainless steel plates support many steel structures, although they cannot be seen from the outside. On the basis that as long as stainless steel materials for building construction have sufficient strength and durability, minor pitting is acceptable, the company obtained in 2002 the approval defined in Article 37 of the Building Standards Law (Approval Nos.: MSTL-0084 & MSTL-0085) for its low-cost and low-carbon 11Cr stainless steel, which affords excellent strength, toughness and weldability and contains a small proportion of carbon. In 2003, for the first time as a bare steel material, the aforementioned stainless steel was approved as Class 3 as defined in the Quality Confirmation Act of the Building Standards Law (Approval No. 406). Then the company commercialized its first chrome steel for building construction "YUS 410W-MS" (11Cr-Ni-LC, N) [6].

In the study on standardization of stainless steel reinforcing bars by JIS that began in 2004 as one of the activities of the Japan Stainless Steel Association, the company proposed that SUS 410 stainless steels should be included, together with SUS 304, SUS 316, etc. As a result, they were specified in JIS G 4322 (Deformed Stainless Steel Bars for Reinforced Concrete)—the first JIS for stainless steel reinforcing bars established in 2008. Concerning SUS 410 reinforcing bars, the company obtained approval under Article 37 of the Building Standards Law (Approval No.: MSRB-0035) for itself. In 2008, the SUS 410 reinforcing bar (product name: NSSD® 410-295 (11Cr-LC)) was adopted for the first time for a symbolic structure[7]. (For details, see the paragraph describing the development of technology for application of stainless steels in architectural and civil engineering structures to help realize a stock-type society, in Section 5.)

Protection lining for pier of marine construction (NSSC 270)

Photo 4 Civil engineering application

In the field of civil engineering, the company has promoted the use of NSSC 304N (18Cr-8Ni-Nb-0.2N) and NSSC 410W (12Cr-LC) for sluice gates and other structures which must be sufficiently strong and durable, NSSC 301L (17Cr-7Ni-LC) and NSSC 436S (18Cr-1.2Mo-Ti-LC, N) for soundproof walls along expressways and louvers of elevated bridges, NSSC 180 (19Cr-0.3Ni-0.4Cu-Nb-LC, N) and special-coated NSSC 220M plate for tunnel interior linings, etc. Recently, a method of welding NSSC 270 stainless steel sheet to the piers of offshore structures to protect them against corrosion was developed[8, 9]. This method began to be applied to power plants and piers of port facilities (**Photo 4**) in the late 1990s. About 400 tons of NSSC 270 was used for the piers of the jetty section in the Haneda Airport Expansion Project now under way.

3.4 Electrical appliances

In this field, stainless steel has been steadily taking the place of pre-coated steel and resin because of its superior corrosion resistance, aesthetic appeal and cleanliness. Today, a wide variety of stainless steel grades and surface finishes, including clear coating, are employed.

A typical example is the use of stainless steel (as opposed to resin) for the drums in washing machines that began in the 1990s (**Photo 5** (a)). With the introduction of fully automated washing machines, it became necessary to increase the rotational speed of the drum during spin-drying of the washed clothes (to 750 rpm or more). As a result, NSSC 430D (17Cr-0.3Ti-LC, N) was adopted for the drum because it was more advantageous than the conventional resin in terms of strength and weight (thickness), corrosion resistance to detergents and bleaches, workability, weldability, aesthetic appeal, cleanliness, and cost, etc. Since then, NSSC 430D has been used as the standard material for the drums of fully automatic washing ma-

(a) Washing machine drum (NSSC 430)

(b) Door panel of refrigerator (NSSC PDX coated with transparent resin)

(c) Hot water tank for electric boiler (NSSC 190)

Photo 5 Home appliance usage

chines.

In addition, the company developed a clear-coated stainless steel product whose surface is free from contamination, leaves no fingerprints, looks attractive and, if necessary, can be made antibacterial. This stainless steel product has been increasingly used as an exterior material for many home electric appliances, such as cooking ranges, dishwashers, rice cookers and water-heating pots. When it comes to applying the clear-coated stainless steel sheet to the door of a bulky refrigerator (Photo 5 (b)), in particular, it was necessary that the clear-coated sheet should be able to be formed by using the same dies as those used to form the ordinary pre-coated steel sheet and that it should have an exceptionally uniform appearance. These problems were solved by applying clear coating to the ultra-formable NSSC PDX (17Cr-0.2Ti-ULC, N) stainless steel using a single-plate printing process. Thanks to subsequent improvements to roll coating technology, it has even become possible to manufacture clear-coated stainless steel sheet on a continuous coating line.

NSSC 190[10], which is the company's representative product in this field, is a stainless steel material featuring excellent SCC resistance. Since its debut, it has been widely used as the standard material for boilers in electric water heaters (Photo 5 (c)). Many electric water heaters these days employ a heat-pump heating system ("ECOCUTE") that contributes to the reduction in CO_2 emissions. NSSC 190 is also used as the principal material for boilers in such water heaters.

In the field of electric appliances, the company supplies two types of original austenitic stainless steel products. One is YUS 27AM (17Cr-7Ni-1.5Si-2Cu), which has a deep-square formability and excellent resistance to corrosion and SCC in hot water exceeding 80℃ and in environments subject to corrosive detergents. This product is applied to dishwasher tanks. The other is NSSC 110M (18Cr-10Ni-2Si-0.8Mo-2Cu), which displays excellent SCC resistance in high-temperature environments containing chlorides. This product is used in heat exchangers.

In terms of the company's products for IT devices, damping stainless steel sheet was adopted for hard disk drive (HDD) covers for the first time in 1998. At one time, it was used for as many as 30 percent of all HDD covers. In addition, as materials for HDD parts, SUS 304 is used for the read-head support, and free-cutting stainless steel wire rod is used for the hub of the drive system.

3.5 Transportation equipment

3.5.1 Vessels

In this field, chemical tankers and LNG vessels are the major consumers of stainless steel. The stainless steel plates that are selected for chemical tankers differ in the level of requirements according to the type and weight of the cargo on board. The main stainless steel materials used for chemical tankers are: SUS 304L and SUS 316L (standard general-purpose stainless steels) for tankers whose capacity is roughly 10,000 tons or less; SUS 316LN for 20,000-ton class tankers because higher strength is required; and NSSC DX1 (dual-phase stainless steel), etc. for 40,000-ton class tankers because still higher strength and better corrosion resistance to seawater are required. For tankers which carry highly corrosive chemicals, such as crude phosphoric acid and sulfuric acid, NSSC DX1 and NSSC 260A, which were developed specially for the purpose, are widely used. In this particular field, clad plates made of stainless steel and ordinary steel are also utilized.

3.5.2 Automobiles and motorcycles

The demand for stainless steels for automobiles began to increase markedly in the late 1980s when control of air pollution ascribable to vehicular exhausts started to be taken more seriously. Although there was a temporary slowdown, demand has been on the rise since the latter half of the 1990s. Today, stainless steels used in automobiles account for nearly 80 percent of stainless steels for transportation equipment.

NSSC 180 (19Cr-0.3Ni-0.4Cu-Nb-LC, N) (former YUS 180) for moldings supported the demand for stainless steel for automobiles in the early days. This material came into being as a result of the effort of all stainless steel makers to develop a substitute for SUS 434 (17Cr-1Mo) at the request of automakers in the face of a hike in the price of molybdenum in 1979. In order to meet the request, it was necessary to develop a new stainless steel containing no molybdenum and displaying stable corrosion resistance in the BA process. Therefore, the company made an all-out effort to establish all the technologies necessary for integrated production of a new stainless steel, including an extra-low-carbon steel refining technology that was difficult to develop in those days, technology for preventing scale defects unique to the steel grade under consideration in the hot-rolling process, and technology for removing or rendering harmless any scale defects that occur in the annealing and pickling process.

As a result, in 1982, the company came up with a low interstitial ferritic stainless steel (YUS 180), which is comparable to SUS 304 in terms of corrosion resistance in ordinary environments. This new stainless steel was adopted by almost all automakers. At the time, former Nippon Stainless Steel Co., Ltd. was also pursuing the development of a similar stainless steel material. Eventually, it led to NAR 160 (16Cr-0.4Cu-Nb-LC). YUS 180 and NAR 160 accounted for the majority of stainless steel materials for moldings adopted by automakers. (They were integrated into NSSC 180 when Nippon Steel & Sumikin Stainless Steel Corporation was created.)

In the process of developing various new uses for NSSC 180, it has become evident that the material has not only excellent corrosion resistance but also a number of desirable properties, such as good workability, high-temperature strength and weldability, which are all well balanced. As a result, NSSC 180 has found a wide variety of applications, including automobile exhaust systems (exhaust manifold, catalyst casing, etc.), electric appliance exteriors, building hardware and utensils. In particular, when the price of nickel hiked, NSSC 180 that features a number of well-balanced properties came to be widely adopted as a substitute for SUS 304 both at home and abroad. At one time, monthly production of NSSC 180 topped 8,000 tons. Today, NSSC 180 is one of the main products of the company.

In the field of automobiles, in which environmental measures are an important technical issue, stainless steel began to be used in earnest for exhaust manifolds and mufflers in the 1980s. Since the latter half of the 1990s, stainless steel has been applied to almost all components of the exhaust systems of automobiles. The company has continually developed new stainless steel products to meet specific performance and functional requirements. Those new stainless steel products are widely utilized. They include: NSSC FHZ (13Cr-1Si-Nb-LC), NSSC 450MS (14Cr-0.5Mo-0.3Nb-0.1Ti-LC) and NSSC 190EM (18Cr-1.6Mo-Nb, Ti-LC, N) for exhaust manifolds; NSSC 409L (11Cr-Ti-LC), aluminum-plated NSSC 409L, NSSC 432 (17Cr-0.5Mo-0.2Ti-LC, N) and NSSC 436S for mufflers; NSSC 305B (19Cr-13Ni-3.5Si) for flexible tubes; NSSC 21M (18Cr-2Al-Ti-LC) for motorcycle mufflers (which serve as catalyst carriers too); etc.

Recently, growing attention is being paid to measures to minimize the evaporation/dispersion of the fuel, too. Under that condition, the company has developed NSSC 436S as a material for the

Railway car (SUS 301L, SUS304)

Photo 6 Transportation

High strength fastener

Photo 7 Application examples of NSSC 550

fuel supply pipe. This material, which is produced by a unique manufacturing process and under unique manufacturing conditions, has excellent resistance to SCC and salt-induced corrosion and can be subjected to severe tube-expansion working.

In addition, in this particular field, with the aim of increasing the power of engines and solving the problem of asbestos, various types of stainless steel products the company has originally developed are utilized. They include a thin, high-strength stainless steel sheet which offers superior spring characteristic to SUS 301L and is suitable for the core of the engine gasket, NSSC 410DA (12Cr-0.07C), which is designed specially for the disk brakes of motorcycles, etc.

3.5.3 Railway carriages and other transportation equipment

Today, stainless steel carriages which are easy to maintain and recycle are familiar to all (**Photo 6**). For the strength members, such as the skeleton, hardened SUS 301L which imparts excellent corrosion resistance and strength to the welded parts is used, and for the structural members, such as the panels, SUS 304 is mainly used. These stainless steels are among the standard grades specified in JIS. Concerning hard SUS 301L for the strength members of railway carriages, JIS specifies extremely narrow ranges of strength and elongation for each grade. Besides, the thickness tolerance is narrow and the production lots are comparatively small. Therefore, this is one type of stainless steel that is difficult to manufacture.

SUS 304 for the panels of railway cars, too, is a difficult material to manufacture, because its surface appearance is strictly defined in JIS. Formerly, Nippon Steel Corporation was the leading maker of hard SUS 301L while Sumitomo Metal Industries, Ltd. was the top manufacturer of SUS 304 for railway carriage panels. Therefore, Nippon Steel & Sumikin Stainless Steel Corporation (NSSC), which has acquired a substantial inheritance from the two companies, has become the major supplier of stainless steel materials in this field. Recently, with the aim of reducing the weight of commuter trains, technology for fabricating car bodies using only SUS 304 honeycomb panels has been studied[11].

3.6 Other stainless steel products

The names of stainless steel grades originally developed by Nippon Steel Corporation, which was the predecessor to NSSC, are prefixed by 'YUS'. YUS 410W for welded structures, which was commercialized around 1972 and which was probably the first stainless steel product of Nippon Steel, and YUS 410W-M, which was an improved version of YUS 410W, have been inherited by NSSC. NSSC 410W-M had long been used for the skeletons of refrigerator cars and marine refrigerator containers. However, with the shift of the principal location for container manufacturing from Japan to Taiwan, South Korea and China, the destinations of 410W-M have changed. Concerning marine refrigerator containers, NSSC 410W has been used for their exteriors and SUS 304 for their interiors. When the price of nickel hiked, NSSC 180 partly replaced SUS 304 as the principal interior material.

NSSC 550 (13Cr-2Ni-2Mo) is the company's original martensitic stainless steel wire rod, which is very hard and has excellent corrosion resistance[12]. When quenched and tempered properly, this steel grade displays exceptionally high strength and hardness—0.2% proof stress 1,150 N/mm^2, tensile strength 1,750 N/mm^2, Vickers hardness (Hv) around 550. In addition, it affords equal or superior corrosion resistance to SUS 304 and has excellent compression formability, which is an important requirement for wire rods. Because of all these factors, NSSC 550 is used for self-tapping screws, and super-strength rivets, pins and chains, etc. which are used in building construction (**Photo 7**).

4. Changes in Situation Surrounding Stainless Steel and NSSC's Response to Those Changes

4.1 Fluctuations in raw material prices

The most widely employed stainless steel in the world is SUS 304 (18%Cr-8%Ni), which is an austenitic stainless steel containing a considerable proportion of costly nickel as can be seen from its composition. Due, at least in part, to the fact that nickel—one of the principal constituent elements of stainless steel—is produced in only a few countries (**Table 2**)[13], it is expensive and subject to wild price fluctuations. This largely accounts for the occasional price hike and sharp price fluctuation in stainless steel products. Since 2005, in particular, the balance between nickel supply and demand has become unstable due to a marked increase in stainless steel production in East Asia, including China. As a result, the international price of nickel has fluctuated wildly. At one time, it topped six times its base price, and then declined sharply (**Fig. 4**).

4.2 Expanding production of stainless steels to help save resources

From the standpoint of minimizing the influence of the extreme fluctuation in nickel prices as mentioned above, growing attention is being paid to ferritic stainless steels which contain very small amounts

Table 2 Production of nickel ore (2007)

Country	Production (× 10^{3}Ni-tons)	Ratio (%)
Russia	288	18
Canada	255	16
Indonesia	188	12
Australia	184	12
New Caledonia	125	8
Colombia	101	6
Philippines	80	5
Others	379	24
Total	1600	100

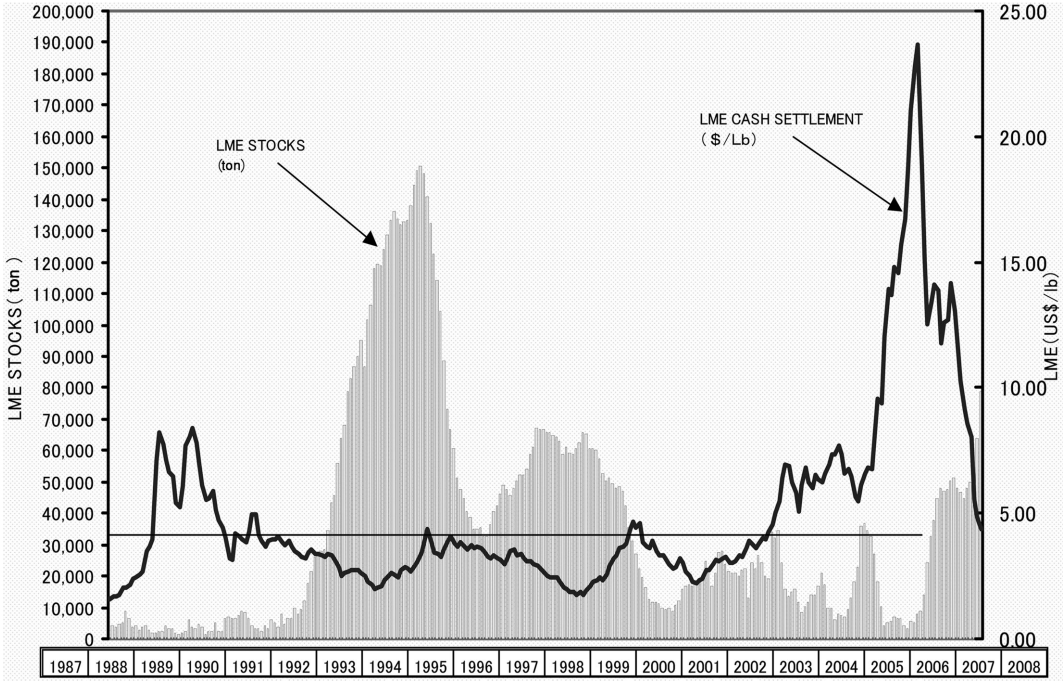

Fig. 4 LME Ni cash settlement and stocks

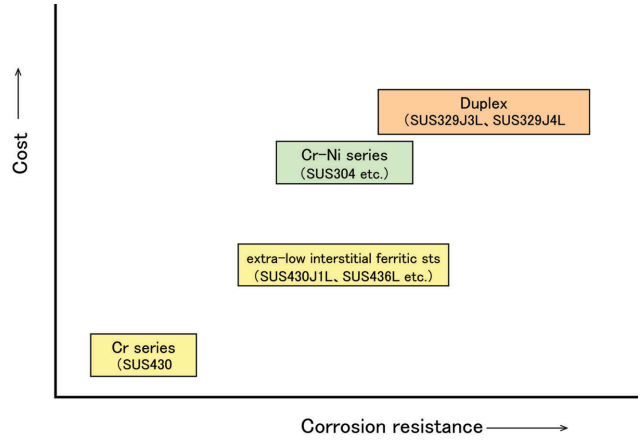

Fig. 5 Commodity concept of extra-low interstitial ferritic and duplex steels

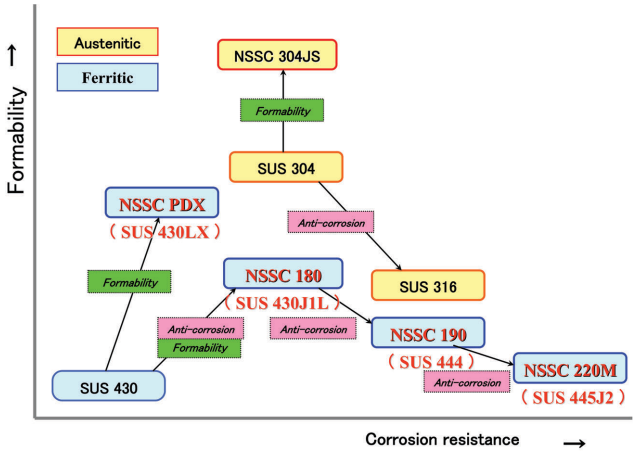

Fig. 6 Performance balance of typical NSSC ferritics

of nickel and duel-phase stainless steels which have smaller amounts of nickel added (**Fig. 5**). These stainless steels are outlined below.

4.2.1 Low interstitial ferritic stainless steels

SUS 430 (17%Cr), which is representative of ferritic stainless steels, does not contain nickel and is inexpensive, hence it is commonly used. However, since SUS 430 has inferior corrosion resistance and workability to ordinary austenitic stainless steel, its application scope is limited. Namely, it is mostly used in devices which are used indoors where the atmosphere is not very corrosive and for devices which require only light working. With the advances in refining technology, such as the VOD process, in recent years, it has become possible to produce extra-low-carbon and extra-low-nitrogen stainless steels on an industrial basis. It has also become possible to compensate for the drawbacks of ferritic stainless steels by adding such stabilizing elements as Ti and Nb. As a result, low interstitial ferritic stainless steels, which offer far superior corrosion resistance, formability and weldability to conventional ones, have been developed. The performance characteristics of the representative low interstitial ferritics of NSSC are shown in **Fig. 6**. The development of low interstitial ferritics dates back to around 1980. Formerly, they were used mostly for special purposes, such as the moldings and exhaust systems of automobiles and the boilers of electric water heaters. Today, against a backdrop of the hike in nickel prices mentioned earlier, NSSC 180–a low interstitial ferritic with good corrosion resistance and formability and which is specified in JIS (SUS 430J1L)–has seen the scope of its application rapidly expand as a substitute for SUS 304, including for kitchen utensils, electric appliance interiors, food storage tanks, building hardware, piping covers, etc. (**Photo 8**).

However, since low interstitial ferritics do not completely match SUS 304 in performance, when it comes to using one, it is necessary to select a suitable grade according to the working environment and

Photo 8 Application examples of NSSC 180

Table 3 Typical characters of duplex (SUS 329J4L)

	—	Duplex	Austenitic steel	
	Grade symbol	SUS 329J4L	SUS 304	SUS 316
	Nominal composition	25Cr-6Ni-3Mo-N-LC	18Cr-8Ni	18Cr-12Ni-2Mo
Mechanical properties	Ys (N/mm^2)	676	314	275
	Ts (N/mm^2)	846	618	588
	El (%)	24.4	59	58
	Hardness (Hv)	279	170	170
Physical description	Density (10^3 kg/m^3)	7.8	7.93	7.98
	Specific heat (0-100℃) [kJ/(kg · K)]	0.46	0.50	0.50
	Thermal conductivity (100℃) [W/(m · K)]	16.3	16.3	16.3
	Linear expansion coefficient (0-100℃) [10^{-6} K^{-1}]	10.5	17.3	16.0
Corrosion resistance	Pitting potential [mV vs SCE]	Approx. 800	Approx. 300	Approx. 400
Formability	Eriksen value (mm)	9.04	13.2	12.7
	CCV (mm)	63.4	38.0	38.4

adopt a working method, working conditions and welding conditions suitable for the selected grade. For example, from the standpoint of formability, stretch forming is mainly applied to SUS 304, which has a large Erichsen value. In the case of a low interstitial ferritic, however, it is necessary to consider applying reduction forming to take advantage of its large Lankford value. In making such tuning, it is indispensable not only to understand the characteristics of ferritics and accumulate working know-how, but also to exchange relevant information with the user. It may be said that the expanding scope of application of ferritics is attributable to the development of new grades and new solutions.

4.2.2 Dual-phase stainless steels

As its name indicates, dual-phase stainless steel ("dual-phase") is a stainless steel with a metallic structure consisting of two phases—ferrite and austenite. The alloying elements are distributed to the two phases in a well-balanced manner. As a result, the dual-phase displays excellent corrosion resistance and strength, even though the amounts of alloying elements added are small (**Table 3**). Since the dual-phase is inexpensive and highly resistant to corrosion, it is being increasingly applied to seawater desalination equipment and various types of chemical plants. In the future, it is expected that high strength dual-phase will help reduce the thickness and weight and improve the safety of equipment to which this stainless steel is applied.

5. Future Prospects

5.1 Change in social demands

The social environment is undergoing major changes—the rapid increase in consumption of resources in the newly industrializing economies; global warming and unusual weather; the obsolescence of social infrastructures, mainly in the fields of building and civil engineering; mounting public distrust in food and rising rates of heinous crimes. Under those conditions, NSSC considers that the medium- to long-term social demands can be represented by these keywords: (1) saving of resources, (2) security and safety, and (3) conservation of the environment and development of new energies. The company's responses to those keywords in its product development are described below.

5.2 NSSC's responses to changing social demands

(1) Saving of resources

As an activity aimed at saving resources, the company continues to develop the high-purity ferritic stainless steels and two-phase stainless steels described in the preceding section. As a high-purity ferritic stainless steel product, the company has brought to market a flexible tube for air conditioners (**Photo 9**). By taking advantage of the desired properties of high-purity ferritic stainless steel, this product is light in weight, easy to install, and inexpensive. Since this product helps to reduce consumption of expensive copper, it is expected that it will be increasingly used in air conditioners for home and business use.

In addition to widening the variety of steel grades, the company

Photo 9 Flexible tube for air conditioner

intends to provide a more comprehensive user's guide so that the user can select the optimum and most advantageous steel grade from the wide assortment of austenitic and ferritic stainless steel products in the face of marked fluctuations in alloy prices in recent years. Concerning dual-phase stainless steels, the company has plans to add sheets and wire rods to the existing plates so as to enhance user convenience. Since dual-phase stainless steel affords excellent strength, it permits reducing the thickness required of anything to which it is applied and hence, it will help reduce the consumption of steel material.

(2) Security and safety

Many of the architectural structures that were built during the period of rapid economic growth have become markedly obsolete after some 40 years of use (**Photo 10**), calling for repairs or refurbishments. Because of its excellent corrosion resistance and many other desirable properties, stainless steel, when applied to those architectural structures, significantly improves their reliability and prolongs their service life. Specifically, stainless steel structural materials can effectively be applied to offshore civil engineering structures which are exposed to highly corrosive environments, buildings in which it is hard to ensure sufficient concrete covering, bridges, and steel towers, etc. In 2008, a ferritic stainless steel reinforcing bar, NSSD 410, which does not contain nickel and hence is cost competitive (**Fig. 7**), was specified in JIS and included in the Guidelines on Design and Execution of Works. Therefore, it is expected that uses for NSSD 410 will expand rapidly.

Thus far, NSSD 410 has been adopted in the "200-Year Housing Model Project", and several historical structures which are expected to remain in existence for a very long time (**Photo 11**), etc. The two-phase stainless steel mentioned earlier also has excellent corrosion resistance and high strength. These desired properties permit using a

Photo 10 Deterioration of reinforced concrete structures

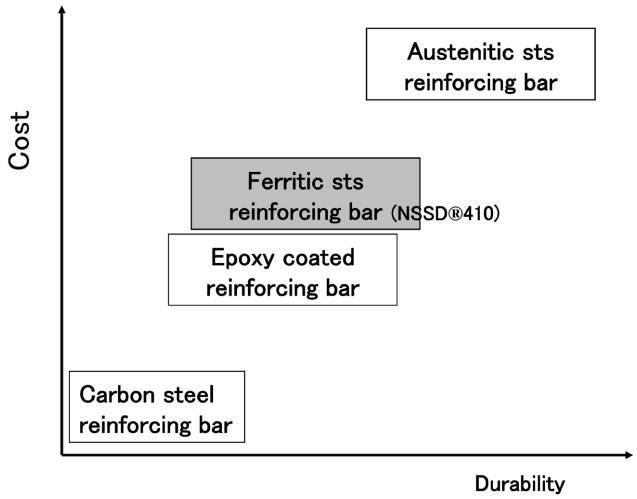

Fig. 7 Commodity concept of NSSD® 410

Photo 11 Application examples for historical buildings and structures (Nezu shrine (Tokyo), Tocho-Ji temple (Fukuoka))

thinner, lighter stainless steel material. Therefore, the two-phase stainless steel greatly helps cut the cost of material. In the United States and Europe, two-phase stainless steel materials are already being used in many fields (e.g. bridges and bridge piers)[14, 15]. In Japan too, it is expected that the application of two-phase stainless steel will be discussed in earnest in the near future.

(3) Environmental conservation and new energies

In the field of environmental conservation, there is an urgent necessity to implement measures to save energy and reduce the consumption of fossil fuels (develop technologies for utilizing new energies) so as to curb global warming. Here are two examples of activities aimed at energy-saving in the automotive field: 1) reducing vehicle weight by using a high-strength stainless steel (two-phase) to decrease the thickness of the car body, etc. and a highly corrosion-resistant stainless steel to eliminate the need to allow for corrosion, and 2) raising exhaust temperatures and recovering waste heat through the development of a new stainless steel material for exhaust manifolds that can withstand higher exhaust temperatures and a highly corrosion-resistant stainless steel that can withstand the latent heat recovered from hot exhaust. Studies on measures to improve thermal efficiency from the same standpoint have also been conducted in the gas and oil industries, etc. Thus, there is strong demand for the development of inexpensive new stainless steel materials with superior corrosion resistance and the establishment of techniques to evalu-

ate them.

Concerning new energies, there are many tasks to tackle. These include: 1) development of new steels that are compatible with biofuels/inferior fuels, 2) development of low-cost steels for economic fuel cells, 3) development of steels for photovoltaic generation, and 4) development of technology for nuclear power generation/nuclear fusion, and so on. We consider that stainless steel is likely to play an important role in each of those fields.

6. Activities to Enhance Integrated Quality Assurance Capability

Quality assurance is one of the fundamentals in manufacturing. Without thoroughgoing quality assurance, really substantial product development cannot be carried out. In other words, no matter how well a new product is planned, it cannot be realized as a marketable one. "Integrated quality assurance capability" means the ability to guarantee the quality of a product throughout the entire process from manufacturing to consumption of the product by the customer. Specifically, it is to positively implement this PDCA (plan-do-check-act) cycle: (P) Understand the customer's need correctly, (D) Design and manufacture a product that meets the need, (C) Check the customer's satisfaction with the product, and (A) Reflect the customer's opinion in the development of the updated product. This is the basic process for complying with quality requirements. The process involves many individuals who are engaged in sales, manufacturing, transportation and secondary working, as well as the customer. It is important that all people concerned should share every piece of necessary information on a timely basis.

NSSC has developed a unique database named "Market Information Sharing System", which is operated systematically. Each of the individuals (reporters) concerned registers the information he or she has obtained in the system, and everyone else can utilize that information. Characteristically, the system is interactive; that is, anyone can comment on the information registered in the system. This enables each person to make his or her action/opinion widely known within the company and to obtain advice/comments from others. On the part of the users of this information, they can obtain the necessary information easily and analyze it from an objective standpoint. Sharing useful information among the people concerned enhances the value of the information, and maintaining it in the form of a database provides a valuable asset to the company. The database can also be used effectively in the case of studies to predict risk, prevent waste, and develop human resources. Today, the company utilizes the database system not only to accumulate information relating to quality assurance, but also to promote the sharing of information about product development, market trends, etc.

7. Conclusion

The market and product development in the field of stainless steels has expanded and progressed with the change in social environment and increased sophistication of customer needs. We consider that it is very meaningful to continue enhancing the "corrosion resistance" and "aesthetic appeal" of stainless steel and the contribution of this versatile material to "total cost minimization", etc. The company continues to apply stainless steel to save resources as one of its most important activities. On the other hand, the company seeks ways to break away from the mere idea of composition adjustment. In addition, the company plans to press ahead with the supply of not only stainless steel materials but also new solutions, including new applications and processing techniques, to its customers so that the uses for stainless steel will further expand in the future.

We believe that expanding the application of stainless steel in the growth fields of environmental conservation and new energies and in the fields of civil engineering and architecture, which demand higher degrees of security and safety, will not only promote the progress of stainless steel but also augment the contribution of stainless steel to society. The history of stainless steel is not very long–some 100 years or so. Therefore, there must remain numerous unexplored areas. The company is determined to continue addressing the challenge of creating new stainless steel products on the basis of accurate understanding (and forecasting) of customer needs while looking to the future.

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