UDC 669.14.018.8

# Product Lineup and Development of Specialty Stainless Steels of Nippon Steel & Sumitomo Metal Corporation

Yoshiaki YAMADE\* Masayuki SHIBUYA Atsuhiko KURODA Ken TAKANASHI

# Abstract

100 years have passed since stainless steel was invented. Stainless steel industry in Japan has increased the production volume steadily along with Japanese economic growth in this period. However, as the competition with foreign countries has intensified, developments of the high-value added products and the pursuit of specialty have been more important than ever in addition to improvement in the cost-competitiveness. Nippon Steel & Sumitomo Metal Corporation has developed higher-performance stainless steels through the collaborative developments with the customers, and put them into practical uses based on our traditional production technology. This paper describes the history, the newly developed specialty stainless steels and our future directions.

## 1. Introduction

2012 marked the 100th anniversary of stainless steel. It was first developed in Europe as steel with non-rusting or rust-resistant properties. Soon after its conception, the study and production of stainless steel began in Japan. The rolling of stainless steel plates in Japan started in the late 1920s, and 20-high Sendzimir mills were introduced in 1958, making it possible to produce great quantities of wide stainless steel sheets offering excellent surface quality. Stainless steel expanded its application in a wide variety of fields including kitchen sinks and other household uses, after which stainless steel production in Japan grew steadily. In 1970 Japan became the world's largest stainless steel producing country, exceeding the U.S.A.

As **Figure 1** shows, although the stainless steel production of developed countries including Japan fell temporarily as a result of the global economic slump in 2008 and other circumstances, world stainless steel production has grown at an annual rate of 5% on average over the last 10 years. As of 2012, Japan is still second in the world in stainless steel production (3.2 million t; all units herein are metric), and thanks to its excellent functionality, demand for stainless steel is expected to grow further in industrial fields such as energy exploration and environmental conservation.

Among the wide varieties of stainless steel for different applications, Nippon Steel & Sumitomo Metal Corporation specializes in the specialty stainless steel products presented in this paper. Although the company's annual production of such products is roughly 30,000 t (accounting for only about 1% of the nation's stainless steel production), it focuses on high-functionality products taking advantage of its completely integrated in-house production facilities, which are capable of a wide range of processes, from steelmaking to hot and cold rolling. The company possesses the expertise to optimally control all of its manufacturing processes , thereby ensuring the required product quality while taking advantage of its R&D laboratories which boast the world's highest technical development capabilities. The company is well known in this sector for its capacity to develop, produce and market high-functionality products that



<sup>\*</sup> General Manager, Dr.Eng., Titanium & Specialty Stainless Steel Unit 2-6-1 Marunouchi, Chiyoda-ku, Tokyo 100-8071



Fig. 2 Japan's stainless steel sheet shipments for different applications (Source: Japan Stainless Steel Association)

meet the sophisticated requirements of customers. The company's specialty stainless steel products include thin sheets and foils for such applications as engine-head gaskets for motor vehicles, corrosion- and heat-resistant steels, and long products (sections).

Figure 2 shows changes in Japan's stainless steel product shipments for different fields of application. Growth of the country's products for transportation and electrical facilities was significant in the 1980s and thereafter, and growth in products for motor vehicles and other modes of transportation has been conspicuous since the 1990s. This has also been the case for Nippon Steel & Sumitomo Metal: development and commercialization of stainless steel products for such applications as exhaust manifolds and engine-head gaskets have been instrumental in the growth of its specialty stainless steel business.

This article presents a history of Nippon Steel & Sumitomo Metal's stainless steel business and its unique product lineup.

## 2. Historical Overview

#### 2.1 Organizational changes

Nippon Steel & Sumitomo Metal's production of stainless steel products, including specialty stainless steel sheets and shapes, traces back to two predecessors: the former Nippon Steel Corporation (NSC) and the former Nippon Stainless Steel Co., Ltd. (NSS). NSC began production of chromium-based stainless steel at Yawata Works in 1921.

NSS was founded in 1934 at Naoetsu, Niigata Prefecture; the plant there still constitutes the main works of Nippon Steel & Sumitomo Metal's stainless steel business. To strengthen its mass production capacity, NSS built its Kashima Works in 1968, and merged with Sumitomo Metal Industries Co., Ltd. (SMI) in 1992. Later, in 2000, to enable quick managerial decision making, SMI separated Naoetsu Works as Sumitomo Metals (Naoetsu), Ltd. Then in 2003, aiming to take advantage of volume efficiency, SMI and NSC reorganized their respective stainless steel businesses and formed Nippon Steel & Sumikin Stainless Steel Corporation, with the former Kashima Works of NSS becoming part of the new company at that time. Later, in 2012, Sumitomo Metals (Naoetsu) temporarily returned to being part of SMI again, but then on October 1, 2012, when NSC and SMI merged into Nippon Steel & Sumitomo Metal, it was reorganized as the Naoetsu Works' Titanium & Specialty Stainless Steel Unit of the new company.

Thus, Naoetsu Works is presently responsible for the company's production of specialty stainless steel products.

# 2.2 Lineup of specialty stainless steel products

The product lineup of Naoetsu Works, the hub of Nippon Steel

& Sumitomo Metal's specialty stainless steel production, and its history are as follows.

After NSS was founded in the 1920s, the works specialized mainly in chromium-based stainless steel, but expanded its product lineup to include austenitic stainless steel after the Second World War. Stainless steel sheets began to be used for kitchen sinks and became a significant part of the steel market. Subsequently, to enhance the functionality of its products and services, NSS expanded its product lineup to thin-gauge sheets (0.3 mm or less) and clad (laminated) sheets, and began etching work of thin sheets in the late 1980s.

In 1996, however, in view of deterioration of market conditions due to the burst of the so-called bubble economy, SMI closed its stainless steel casting business at Naoetsu Works, which had manufactured varieties of valves for piping, and in 1997 also closed its sheet etching business. Further, in 2003 when Nippon Steel & Sumikin Stainless Steel was organized, the activities of Naoetsu Works regarding stainless steel sheets for general applications, such as JIS SUS 304, were transferred to the new company for the sake of volume efficiency.

The present product lineup of Nippon Steel & Sumitomo Metal's specialty stainless steel business is roughly divided into three parts: long products (or sections), plates, and sheets. The sheets do not include sheets for the external finishing of buildings, electrical appliances, or other mass-produced general-use products. Instead, the company specializes in small-lot, high-added-value products such as very thin gauge sheets and clad sheets, as well as sheets laminated with chromium and/or aluminum sheets processed by rolling.

## **3. Manufacturing Processes and Facilities 3.1 Long products**

The company manufactures angles and channels of stainless steel in a wide variety of sizes. Most commonly, JIS SUS304, SUS316 and other steel grades for general applications are produced through hot rolling and heat treatment processes.

Billets and blooms to be rolled into these products are continuously cast at Wakayama Works, thentransported to Naoetsu Works for hot rolling. At Naoetsu, they are cut to prescribed lengths and heated in a reheating furnace to rolling temperature. The heated billets/blooms are then rolled continuously into long products with prescribed final dimensions, going through roll gaps (or roll passes) of different shapes at rolling mill stands. Here, products of small cross-sectional areas, such as small angle stainless steels, are rolled through many passes into long pieces. To make the mill equipment compact, repeaters are employed to redirect the rolled materials by 180 degrees between passes (see **Fig. 3**). Design of these repeaters



Fig. 3 Hot rolling mill for stainless steel long products



Fig. 4 Available size range of stainless steel equal angles

is critical, especially for angles with complex cross-sectional shapes. Simulation technology and equipment improvements based on longaccumulated operation experience have solved problems and stabilized rolling operations.

After being rolled into their final dimensions, the shapes undergo straightening, heat treatment, shot blasting, pickling, and finally inspection to check appearance and dimensions before being shipped as finished products.

Nippon Steel & Sumitomo Metal's stainless steel shapes are characterized by a wide range of sizes: as shown in **Fig. 4**, the company's unique sizes expand mainly toward the heavy section side.

While most of the angles and channels are rolled at Naoetsu, Hshapes and some channels with special dimensions are manufactured outside the company through hired rolling, although these products still also undergo integrated quality control by Naoetsu personnel before shipment.

#### 3.2 Plates

Stainless steel heavy plates are now manufactured at Naoetsu through the hot rolling of slabs, which used to be continuously cast at Wakayama; **Fig. 5** shows the plate rolling mill. The hot-rolled plates are processed into final products through heat treatment, leveling and pickling.

Common grade stainless steels are rarely rolled as plates. Generally, rolled plates consist of special grade heat-resistant steels and other steels having poor workability at high temperatures. It is important that the rolling temperature of such low-workability materials be controlled within a prescribed range. For the ease of precise temperature control, the roll stand of the 2-high reversing plate mill is located close to the reheating furnace.

For example, large amounts of sulfur are added stainless steels, such as JIS SUS 303, to improve machinability. As a result, however, such steels easily crack under hot working, and their slabs cannot be hot rolled as continuously cast. As a countermeasure, a hot press is provided to the slabs before plate rolling to improve hot workability.

As stated above, compact equipment arrangement and the effective use of auxiliary facilities allow for production of unique special alloy products that would otherwise be impossible in mass production facilities.

## 3.3 Sheet and strip

The first manufacturing step for sheet products of stainless steel and pure nickel is to melt the metals to prescribed chemistry and continuously cast them into slabs. At Nippon Steel & Sumitomo Metal, this is done at Wakayama Works. The slabs are then hot rolled into hot bands, or hot coils, at Yawata, and these are finally



Fig. 5 Hot rolling mill for stainless steel plate



Fig. 6 Precision rolling mill for finish rolling of thin stainless steel sheets and coils

cold rolled at Naoetsu.

Cold-rolling processes are explained below, using thin-gauge sheets for springs as an example. First, hot bands are annealed and then cold rolled to an intermediate thickness. The sheets of the intermediate thickness are then annealed again, cold rolled to final thickness, and temper rolled to give the material a prescribed hardness. The reduction at temper rolling is defined in consideration of the hardness indicated by the customer. The temper-rolled sheets are flattened through a tension leveler, and then shipped as finished products.

The rolling of hot bands to an intermediate thickness is done on a 6-high or 20-high reversing rolling mill, and rolled to their final thickness on a 6-high precision rolling mill (see **Fig. 6**).

Using commonly applied standards such as JIS, stainless steel sheets for spring use are classified according to their hardness into 1/2H, 3/4H, H, etc. ("temper grades"). It is important to control temper rolling conditions so that product hardness falls within the desired range. One example where hardness is controlled by volume fraction of hard, work-induced martensite formed during temper rolling is in austenitic stainless steels for spring use, such as JIS SUS 301. The formation of martensite, however, depends largely on temperature and other rolling conditions, in addition to the reduction ratio, and it is essential that the rolling operation be controlled meticulously, taking into consideration overall conditions, such as steel chemistry and ambient temperature.

Another essential process for product quality is annealing. Hot bands are annealed through a continuous line comprised of a section in normal atmosphere and a pickling section. Conversely, coldrolled sheets are finish annealed continuously in a mixed non-oxidizing atmosphere of nitrogen and hydrogen before temper rolling.

In addition to softening the material, this final annealing is decisive for the material surface properties, such as wettability of sheets for etching use. For this reason, control of the annealing atmosphere is of great importance, albeit the open furnace is a continuous process.

Sheet surfaces must be free of defects. Surface defects, especially in sheets for spring use, will lead to premature fatigue failure in the final product, so thorough defect control is imperative. Every practical measure is taken at each manufacturing stage to prevent surface defects of hot bands. CCD cameras are used during the final inspection before shipment to prevent defective products from being shipped inadvertently.

In addition to stainless steel sheets, Naoetsu Works also produces thin sheets of pure nickel in quantities for applications such as lithium ion battery electrodes; they are produced basically through the same processes as those for stainless steel sheets. Besides these sheet products, Naoetsu also manufactures stainless steel and nickel foils that are 20  $\mu$ m or more in thickness; a 12-high cluster mill is used for rolling foils. **Figure 7** shows the available size range of these sheet products.

Yet another unique flat product of Naoetsu is metal-clad sheets. They are manufactured through either hot or cold rolling.

In the hot rolling process, thick slabs of different metal materials are layered, welded together by electron beam welding, heated in the furnace, and then hot rolled. These slabs are then cold rolled into thin sheets in the same way as stainless steel sheets. Coils of carbon steel sheets clad with JIS SUS 304 stainless steel on both sides, for instance, are produced by this method. The product takes advantage of the excellent induction heating properties of carbon steel at its



Fig. 7 Available size range of stainless steel sheets and coils

core, and high corrosion resistance of stainless steel on its surface layers – it is often used for high-grade cooking pots and the like.

On the other hand, in the cold rolling process, stainless steel and aluminum sheets in coils are heated to a prescribed temperature and then continuously laminated together by rolling. For more details on these types of clad sheet products, see another article in the present issue.

#### 3.4 Research and development organizations

Because the stainless steel business of the company's Titanium & Specialty Stainless Steel Unit specializes in specialty stainless steel products (as stated earlier), unflagging technical research and development for new products is essential.

Many specialist researchers are engaged in R&D activities at Steel Research Laboratories under policies set forth by the Technical Research & Development Bureau. In addition, many specialized researchers are employed at Naoetsu on a permanent basis to investigate field problems and accelerate development of new products. Close cooperation is maintained between field production engineers and R&D organizations in regard to basic technologies for rolling, annealing, and other production processes. Thus, the plant's production activities are backed up by substantial R&D capabilities that are among the best in the world.

**Table 1** lists the technical awards Nippon Steel & Sumitomo Metal has received over the last five years for its specialty stainless steel products. The company is proud to have received the Technical Development Award from the Japan Institute of Metals for four consecutive years, in recognition of its joint efforts with customers to develop products and their applications. It is imperative in this industry to continue R&D activities for new products and their potential applications.

## 4. Principal Products

#### 4.1 Long products

From among the wide variety of stainless steel long products, Nippon Steel & Sumitomo Metal produces the shapes (angles, channels and H-sections) and flat bars illustrated in **Fig. 8**. With regard to steel grades, JIS SUS 304 is excellent in corrosion resistance and weldability, and accounts for a good part of these products. Other steel grades include: SUS 316 for use in severely corrosive conditions, such as chemical plants; SUS 304 and SUS 316 modifications containing less carbon (SUS 304L and SUS 316L); and high-strength SUS 304A and SUS 316A (both under JIS G 4321), for building structure use.

Since stainless steel is superior to ordinary carbon steel in corrosion resistance, it requires no protective coating, making mainte-

Year	Award	Subject
2008	The Japan Institute of Metals Technical Development Award	Development of fine grain stainless steel for high fatigue strength cylinder
		head gasket
2009	The Japan Institute of Metals Technical Development Award	Development of stainless steel foil for PEFC separator
2010	The Japan Institute of Metals Technical Development Award	Development of heat resistant stainless steel for high temperature heat ex-
		changer
	Prize of Science and Technology by the Minister of Education,	Development of high fatigue strength stainless steel for gasket
	Culture, Sports, Science and Technology	
	Sokeizai Center. Sokeizai Industry Technology Award	Development of heat resistant stainless steel for exhaust manifold
2011	The Japan Institute of Metals Technical Development Award	Development of fine precipitation dispersed stainless steel for high pres-
		sure combustion cylinder head gasket

Table 1 List of awards by the members regarding stainless steels in recent 5 years

nance more economical. Product surfaces are finished through pickling (called No. 1 finish under JIS G 4317) or hairline polishing, selected according to the intended application.

These long products are marketed through major specialist distributors who keep considerable amounts of products in stock, covering different section sizes and lengths, to respond to customer requests promptly and efficiently.

The principal applications of stainless steel long products, relevant issues and typical applications are as follows.

- Building construction: as a result of revisions to the Order for Enforcement of the Building Standards Act of Japan in 2002, stainless steel has become applicable for building structures like ordinary carbon steel sections, and it is now possible for buildings to make good use of the excellent durability of stainless steel (see Fig. 9).
- Civil construction: stainless steel shapes have been used for such applications as frames and rails, and for structural reinforcements for dams, water gates and the like. Other typical uses include structures for underground motorway facilities, and similar facilities involving exhaust-gas environments.
- Food industry and household kitchens: in appreciation of its high level of cleanliness without rusting in wet conditions, stainless steel shapes have been widely used for sinks, gas burners, counter tops and other kitchen facilities.
- · Plant equipment: stainless steel long products are also used for





C half-round bars

Rolled Flat bars Slit Flat bars

Channels

# Fig. 8 Kinds of stainless steel long products



Fig. 9 Application example for stainless steel sections (courtesy of Hotel Kirishima Castle)

structural members and reinforcements at petroleum, chemical and other plants, making the most of their excellent corrosion resistance.

The stainless steel angles and channels manufactured by Nippon Steel & Sumitomo Metal and other Japanese steelmakers are characterized by small corner radii and good surface quality, which help differentiate them from the products of other countries. **4.2 Plates** 

#### **4.2** Plates

Stainless steel heavy plates are used especially for their heat and corrosion resistance properties. Nippon Steel & Sumitomo Metal offers unique products for both of these applications.

#### (1) Heat-resistant applications

Stainless steel is more heat-resistant than carbon steel. Austenitic stainless steel, in particular, is widely used for high temperature applications owing to its heat resistance, which is superior to that of other stainless steels. Typical uses for plates made from austenitic stainless steel include supports for the heat-transfer tubes of thermal power plant boilers and structural members of industrial furnaces; JIS SUS310S is commonly used for these applications. Austenitic heat-resistant stainless steel NSSMC-NAR-AH4, which Nippon Steel & Sumitomo Metal developed, has heat resistance exceeding that of SUS310S. This steel grade was developed originally for the pressurized fluidized-bed boiler equipment of coal-burning combined power plants offering enhanced efficiency; it is superior to SUS310S in high-temperature strength, creep and oxidation resistance, and weld crack sensitivity. And because it has high microstructural stability in the high-temperature range of 700 to 900°C, it is resistant to embrittlement thanks to intermetallic compound ( $\sigma$ phase) precipitation, making it effective in extending the service life of structures used at high temperatures. NSSMC-NAR-AH4 is therefore used for an increasing number of applications, including steelmaking facilities (reheating furnaces, burner nozzles, heat-insulating plates, etc.), heat-treatment furnaces for other industries (muffles, jigs for supporting heating objects, etc.), gasification incineration furnaces and other incinerators, and rotary kilns (see Fig. 10). (2) Corrosion-resistant applications

Different grades of stainless steel are used in various kinds of corrosive environments, some in fresh water or similarly mild conditions, others exposed to strong acids; various types of materials are selected in consideration of the chemistry, concentration, temperature and other conditions of corrosive agents. Nippon Steel & Sumitomo Metal has developed a wide variety of stainless steels that respond well to corrosive conditions. Because many stainless



Fig. 10 Application example for AH-4 (courtesy of Kanto Yakin Kogyo Co. Ltd.)



Fig. 11 Corrosion rate (mm/year) of NSSMC-NAR-SN-1 (subjected to sensitization for 2 hours at 650°C) in nitric acid solutions

steel plate products are of steel grades commonly produced at the company's Pipe & Tube Unit, it is possible to supply plates and seamless tubes of the same steel grade for the same chemical plant projects, which helps give customers freedom in plant design. The company has also worked with customers to jointly develop various new grades of stainless steel. The company's capacity to respond flexibly to high-end customer requirements, and the technical expertise it has accumulated as a result, are two of the advantages offered by its specialty stainless steel business. Three typical examples, NS-SMC-NAR-SN-1 which is resistant to nitric acid, NSSMC-NAR-DP-3W which is resistant to chlorides, and NSSMC-NAR-DP-28W for urea plants, are presented below.

As shown in Fig. 11, NSSMC-NAR-SN-1 for anti-nitric-acid applications exhibits excellent corrosion resistance in environments up to a 100% concentration of nitric acid, which conventional grades of stainless steel cannot withstand. In a low-concentration environment, a strong passivation film forms on stainless steel surfaces due to the oxidizing ability of nitric acid. Conventional grades of stainless steel such as JIS SUS 304L and SUS 310ELC have good corrosion resistance, but in a high-concentration environment, especially when the nitric acid concentration is 98% or more, such stainless steel surfaces often become excessively passivated, and corrosion due to intergranular attack advances rapidly. For this reason, tanks of aluminum, titanium or glass-lined carbon steel have been used for handling nitric acid in high concentrations. These materials, however, have drawbacks: for instance, aluminum corrodes quickly when nitric acid concentrations are 95% or lower, and glass lining is brittle and its maintenance is troublesome. In contrast, NSSMC-NAR-SN-1 is strong, tough, and highly resistant to nitric acid in whatever concentration, and is therefore suitable for structures for large plant equipment. It has therefore been used for nitric acid handling facilities, including ships, tanks and piping.

NSSMC-NAR-DP-3W, designed for anti-chloride supplications, is a super-duplex stainless steel having a pitting corrosion resistance index of 42 or higher, and is excellent in resisting the corrosive effects of chlorides. It was developed as a material for heat exchanger pipes and piping used in severely corrosive environments with high chloride concentrations, and has been used for such widely varied applications, including seamless tubes for undersea pipe lines. Even at weld joints it is more corrosion-resistant than other high-Mo super-duplex alloys, and is highly weldable by TIG or shielded arc welding. It has been used for salt production plants, soy sauce tanks, sea water pumps, etc., and its application is expected to expand further.

NSSMC-NAR-DP-28W (28Cr-8Ni-Mo-W-N) was developed

jointly with Toyo Engineering Corporation (TEC), originally for application at urea synthesis plants; it is a dual-phase steel suitable for the extremely corrosive conditions of such plants. Since its development in 2003, it has been used for plants that employ the ACES21 process, which is an energy-saving urea synthesis process developed by TEC. Heavy plates of this steel are rolled at Naoetsu Works, while seamless pipes of this grade are manufactured by the Pipe & Tube Unit at Amagasaki Works.

Demand for urea has been growing over the last few years owing to its expanded use for fertilizers and cosmetics, and as a reducing agent for diesel engine exhaust gases. This has resulted in an increase in the number of urea plants.

Highly corrosive ammonium carbamate forms as part of the urea synthesis process, so steel materials used for urea plant facilities must be high strength and highly resistant to corrosion. NSSMC-NAR-DP-28W, one steel developed by the company, is intensively used for urea plants since it is one of the most suitable steel materials available in the market, thanks to its high strength and excellent resistance to attack by ammonium carbamate. Owing to its high chromium content and low nickel content, it maintains good corrosion resistance in high alkali environments, even when amines are found together. Because it is as corrosion resistant as 30Cr stainless steels, and is more easily available in the market, its use for anti-alkali applications is also expanding.

(3) Nuclear applications

Stainless steel is intensively used for nuclear power plants. Nippon Steel & Sumitomo Metal produces plates belonging to the 304-family of stainless steels, which contain roughly 1% boron for applications for racks and casks for the intermediate storage of waste fuels. Because natural boron contains roughly 20% <sup>10</sup>B in a large neutron-absorption cross section, 304-family steels containing boron have a high neutron-absorption capacity. Thanks to this, and to their high strength for structural uses, these steels corrode only a little in boric acid solutions. But because of their poor hot workability, rolling them into plates is not easy. Naoetsu Works has been successful in supplying plate products composed of a material that makes good use of both the mill arrangements and the production know-how the company has built up over the years. (4) Hired rolling of stainless steel plates

Taking advantage of the short distance between the reheating furnace and the mill stand, and consequently the small temperature drop before rolling starts, Naoetsu Works receives orders for the hired rolling of steel grades that involves complex rolling operations. Mill personnel are accustomed to rolling JIS SUS 303 and similar grades that are prone to edge cracking during hot rolling. Making the most of their expertise in complicated operations such as multi-heat rolling of small-lot products and rolling of small-size plates, the factory has an admirable track record of rolling special products, such as target materials for sputtering, which most other mills cannot produce.

#### 4.3 Sheet and strip

Thanks to integrated manufacturing processes ranging from handling molten steel to product finishing, Nippon Steel & Sumitomo Metal's stainless steel sheet business is characterized by a capacity to develop and offer specialty products tailor-made for customer needs. Such specialized products often find wider applications, as do other high-functionality products developed in-house.

The principal users of high-functionality sheet products are the automotive, electronic, and energy industries. For example, rechargeable batteries are one field of application showing significant growth over the last few years in the energy sector. These highfunctionality products are not necessarily used in large quantities, but they often make up an indispensable part in certain applications and industrial fields.

The high functionality of such products results from alloy designs that result in unique characteristics through the addition of such elements as niobium, nitrogen and rare earth elements. But in most cases tangible effects are obtained only when delicate alloy design is combined with field production technologies, such as precision control of production processes to bring about an intended crystal structure, or effective use of nitrogen adsorption during annealing. High-functionality products are generally more expensive than those for general use, but users prefer them because of benefits that justify the price difference. Nippon Steel & Sumitomo Metal has developed new stainless steel products having any one of the following characteristics (internally called precision-rolled products), and has cultivated markets for them: (i) sheets 0.3 mm or less in thickness; (ii) sheets having strict gauge tolerances; and (iii) coldrolled sheets shipped without finish annealing. Such products are presented in more detail in the following sub-section. 4.3.1 Typical precision-rolled products

(1) Sheets for gaskets (see Fig. 12)

Cylinder-head gaskets installed between the cylinder heads and

cylinder blocks of automotive engines are made mostly of stainless steel sheets of JIS SUS301H, and are approximately 0.2 mm in thickness. Nippon Steel & Sumitomo Metal has focused on developing two kinds of material for their application: steel grades of higher functionality, and grades which are more economical. These have been successfully included in the company's product lineup.

Efforts to enhance functionality resulted in the development of NSSMC-NAR-301L HS1 (hereinafter "HS1"), which has excellent fatigue strength. Every time fuel is ignited in an engine cylinder, the cylinder head is lifted. Cylinder-head gaskets must have good spring properties so as to follow the head lift and prevent gases from escaping, and must also have high fatigue strength to withstand repeated stress. With new developments resulting in reduced engine block weight and increased combustion pressure to improve efficiency, required changes include an increase in head lift and higher gasket fatigue strength. HS1's unique chemistry offers a lower carbon content and increased nitrogen and niobium content, compared with JIS SUS 301, and its fatigue strength is increased by controlling the manufacturing processes in order to refine average crystal grain size to 1 to 2  $\mu$ m (see Fig. 13).

After HS1 was developed, maximum combustion pressure was further increased in pursuit of even higher fuel efficiency, and NS-SMC-NAR-301L HSX (hereinafter "HSX") was developed as a new, higher functionality gasket material capable of coping with tougher use conditions, then launched onto the market. During HSX heat treatment in a bright annealing furnace, nitrogen adsorption on the sheet surface layers is accelerated to improve fatigue properties and static strength above those of HS1.

NSSMC-NAR-403 2D-Q has been developed as an alternative, more economical gasket material; it is manufactured by quenching a grade of martensitic stainless steel through a bright annealing furnace. This steel contains a reduced number of alloy elements, and is also used for other applications as an economical material for its spring properties.

(2) Sheets for precision-work applications

Electronic device components, which are sometimes manufactured through photo-etching or laser-beam machining, must have



Fig. 12 Lineup of gasket materials of Nippon Steel & Sumitomo Metal



Fig. 13 Head gasket of NSSMC-NAR-301L HS1

high dimensional accuracy, and the materials they are made from must be flat and deform as little as possible after they are worked. Taking advantage of the expertise and know-how built up during etching work at Naoetsu Works, the company has developed SUS 304 H-SR sheets and placed them on the market. These products are characterized by low residual stress due to tension leveling and subsequent heat treatment, and improved adhesion of the photoresist for photo-etching work on sheet surfaces. The improved photoresist adhesion is obtained by reforming the oxide film that forms during the stress-relieving heat treatment.

Oxide film reforming has been confirmed to be effective also at reducing press die wear, and this is advantageous also for the manufacture of retainers for miniature bearings, and for similar requirements for large amounts of press forming work.

More recently, Nippon Steel & Sumitomo Metal has developed and marketed SUS304 H-SR2, which has less deformation after photo-etching and laser working, and has attracted customer appreciation. This steel has the same chemistry as JIS SUS304. Its fine properties are obtained through a delicate control of process conditions.

Additionally, by combining the manufacturing processes of SUS 304 H-SR with the crystal grain refining technology it developed for the gasket material, the company has developed NSSMC-NAR-301L SE1 (hereinafter "SE1"), which is superior to SUS 304 H-SR and H-SR2 in terms of workability. SE1 has been much valued by users as a high-functionality product with excellent smoothness in etched surfaces, and laser-beam machining properties (see **Fig. 14**). For electronic device surface mounting, thin stainless steel sheets are used as stencils (metal masks) for printing adequate amounts of soldering paste in exact positions on substrate surfaces. With increased surface mounting density for electronic devices such as cell phones and other portable devices, the use of SE1 is increas-



Fig. 14 Smooth laser-machined surfaces of NSSMC NAR-301L SE1

ing thanks to its laser-beam machining properties, which dictate printing quality.

(3) Pure nickel foils

Highly corrosion-resistant pure nickel foils are used as internal leads for the negative electrode of lithium ion rechargeable batteries. Nippon Steel & Sumitomo Metal supplies the material in final sizes of 0.05 to 0.1 mm in thickness and 2 mm or more in width. Taking advantage of its integrated processes that range from molten metal conditions to foil rolling, the company enjoys customer satisfaction for its high-quality foils for this application. Product features include high contact reliability due to well-controlled minor elements, and minimum burs ensured by precision slitting.

4.3.2 Stainless steel sheet and strip for other applications

(1) Heat-resistant sheets

Nippon Steel & Sumitomo Metal produces thin sheets of NS-SMC-NAR-AH-4, which was originally developed for plates, and supplies them for the exhaust manifolds of automotive engines. Because of its excellent high-temperature strength and oxidation resistance, this material allows for the use of thinner sheets, which is advantageous for gas cleaning at cold start because of the smaller heat capacity.

Thin sheets of different grades of stainless steel are used for other heat-resistant applications as well. For such applications, the company has developed NSSMC-NAR-AH-7, which is highly resistant to oxidation at high temperatures and high humidity, and NSSMC-NAR-AH-1, which has excellent oxidation resistance in high-temperature environments containing chlorine. The former has been used for heat exchangers operating in hot gas atmospheres containing water vapor, the latter for the sheathed heaters of cooking facilities for household and commercial uses. These alloys are designed to decrease the content of Ni and other expensive elements, thereby offering economical advantages while maintaining excellent properties.

## (2) Metal-clad sheets

Aluminum/stainless steel clad sheets are produced by laminating a sheet of aluminum, which is excellent in thermal conductivity, with a stainless steel sheet, whose ferritic qualities ensure good induction heating. The sheets are used for the induction-heating pots of rice cookers and similar apparatus. Besides such two-layer sheets, three-layer stainless steel/aluminum/stainless steel sheets are also



Fig. 15 Cooking pot for induction-heating rice cooker: stainless steel/ aluminum clad sheet with copper coating

used for different applications. Commercially pure titanium sheets are sometimes used in place of the stainless steel sheets. It is also possible to join long, wide coils of clad sheets to make a single comprehensive one; the high reliability of the joints helps enhance productivity during the forming and final product working stages.

Some rice-cooker pots have a copper surface coating to improve induction heating properties. Such pots are manufactured at Naoetsu by blanking two-layer aluminum/stainless steel sheets into discs, then plating them with copper to a prescribed thickness (see Fig. 15).

Three-layer clad sheets of hard martensitic stainless steel and aluminum with excellent thermal conductivity are supplied for applications requiring strength and heat radiation.

(3) Pure nickel sheets for electrodes

Pure nickel, which has good corrosion resistance and low hydrogen overvoltage, is used industrially for electrodes for electrolysis. For electrolysis to produce sodium hydroxide, for instance, pure nickel is used for the cathodes, and titanium for the anodes. Nippon Steel & Sumitomo Metal is one of the few companies capable of supplying the two materials together.

(4) Stainless steel sheets for fuel cells

Fuel cells have clean energy purposes, and their use is expected to grow significantly. Fuel cell separators must have high corrosion resistance, and low, stable contact resistance. Stainless steel has high corrosion resistance owing to the passivation films on its surfaces, but its contact resistance is high. To solve this problem, Nippon Steel & Sumitomo Metal has developed a new stainless steel sheet product that satisfies both requirements: by adding new alloy elements, the electro-conductive compounds are made to deposit on the sheet surfaces. The product is expected to encourage wide applications as fuel cell use expands.

## 5. Future Prospects and Closing

The stainless steel industry has grown by developing one new application after another, making the most of the material's high functionality. Nippon Steel & Sumitomo Metal's business has maintained the company's business model: promoting the functionality of specialty stainless steel products. In view of increasingly tough international competition for market share, the need grows for unflagging research and development to enhance product functionality and strengthen cost competitiveness.

With this in mind, and making the most of its years of manufacturing expertise and close cooperation with customers, the company intends to place more emphasis on developing new products for automotive applications, including heat-resistant materials, gasket sheets, batteries, and other energy-related applications. The compa-

ny's highly competitive position in the pipe and tube sector will help it cultivate more market opportunities for specialty stainless steel products in the energy and chemical industry fields. The company also intends to further enhance its cost competitiveness in these fields through production yield improvements, optimizing and stabilizing its manufacturing processes while also introducing new ones.

#### References

- 1) Science and New Technologies of Stainless Steel, 1st Edition. Tokyo, Japan Stainless Steel Association, 2011
- 2) International Stainless Steel Forum Website: Statistics of Crude Steel Production
- 3) Japan Stainless Steel Association: Statistics of Orders for Stainless Steel Flat Products by Market Classification. 2013
- 4) Nippon Stainless Steel Co., Ltd.: "Shiroi Hagane" 50 Years of Nippon

Stainless Steel (A Company History). 1984

- 5) Matsuda, T.: Nippon Stainless Technical Report. No. 23, 73 (1988)
- 6) Kondoh, K. et al.: Materia Japan (Bull. Jpn. Inst. Met.). 36 (6), 637 (1997)
- 7) Ogawa, K. et al.: Materia Japan. 51 (2), 67 (2012)
- 8) Nishiyama, Y. et al.: Sumitomo Metals. 49 (4), 50 (1997)
- 9) Katsurai, T.: Honda R&D Technical Review.12 (1), 151 (2000)
- 10) Adachi, K. et al.: Materia Japan. 47, 36 (2008)
- 11) Nishiyama, T. et al.: Honda R&D Technical Review. 20 (1), 105 (2008)
- 12) Adachi, K. et al.: Materia Japan. 50, 120 (2011)
- 13) Hirahara, K.: Sokeizai. 49 (1), 19 (2008)
- 14) Fujisawa, K.: Sokeizai. 53 (1), 33 (2012)
  15) Shibuya, M.: Convertech. 40 (7), 75 (2012)
- 16) Ishii, K. et al.: Honda R&D Technical Review. 14 (2), 69 (2002)
- 17) Shibuya, M. et al.: Sokeizai. 51 (12), 30 (2010)
- 18) Doi, D. et al.: Sumitomo Metals. 45 (5), 145 (1993)
- 19) Iwasaki, S. et al.: Sumitomo Metals. 49 (4), 38 (1997)



#### Yoshiaki YAMADE

Dr.Eng. General Manager, Specialty Stainless Steel Technology Titanium & Specialty Stainless Steel Unit 2-6-1 Marunouchi, Chiyoda-ku, Tokyo 100-8071



Atsuhiko KURODA Dr.Eng. General Manager, New Production Technology Titanium Technical Service & Solution Dept. Titanium & Specialty Stainless Steel Unit







Ken TAKANASHI

General Manager, Titanium & Specialty Stainless Steel Unit