Recent Growth in Demand for Stainless Steel with Multi-Functionality*

Sadao Hasuno
Staff Assistant General Manager, Stainless & Special Steel Business Planning Dept.

Masaji Shiraishi
General Manager, Stainless & Special Steel Business Planning Dept.

Synopsis:

The development of stainless steel production facilities and steel grades in Kawasaki Steel supports the great increase in demand of stainless steels. Cr-ore smelting reduction, powerful hot rolling mill and tandem mill rolling were developed and applied especially to ferritic stainless steels in many fields such as automobile, construction and other general uses. Kawasaki Steel is now characterized by the high production ratio of ferritic stainless steel.

1 Introduction

At the present time, stainless steel is continuing to enjoy strong growth in a wide range of fields as a steel material which can be manufactured with a variety of desirable features, including not only corrosion resistance, but also heat resistance, designability, and high strength. As shown in **Fig. 1**, the actual results of orders received for stainless steel sheets in Japan, classified by application,[1] increased remarkably from 230 000 tons in 1967 to 1.1 million tons in 1997. However, in 1998, orders declined from the previous year due to the recession in the Japanese economy. Increases have been recorded in all fields, but the growth in construction and transportation has been particularly notable. This increase in orders was supported by a dramatic increase in production capacity and improved product quality, together with the cultivation of new demand. Kawasaki Steel has expanded the applications of stainless steel by developing production technologies and new products with particular emphasis on ferritic stainless steels.[2] This report pesents an outline of the features of the production process at Kawasaki Steel and the lines of products which are contributing to expanded demand for stainless steel.

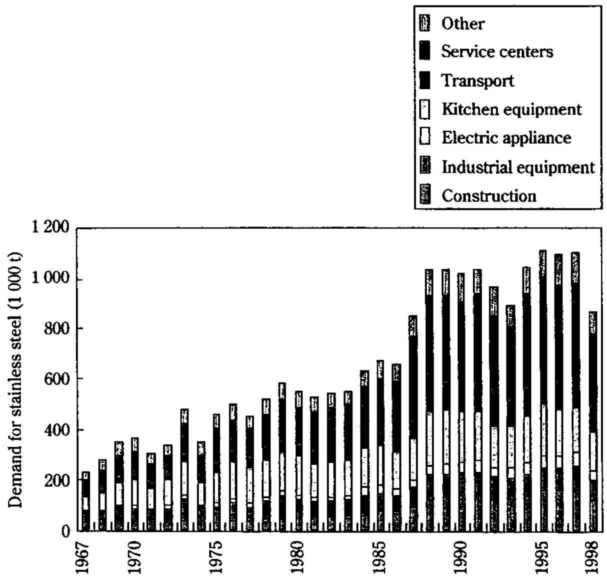


Fig. 1 Trend in stainless steel demand for several end uses in Japan (Source: Japan Stainless Steel Association)

2 Features of Stainless Steel Production Technology at Kawasaki Steel

2.1 Steelmaking Process

The conventional process comprising the electric arc furnace–AOD–(VOD)–CC, using FeCr alloy and scrap as raw materials, is still frequently employed to melt stainless steel. However, to realize continuing quantita-

* Originally published in *Kawasaki Steel Giho*, **32**(2000)3, 215–221

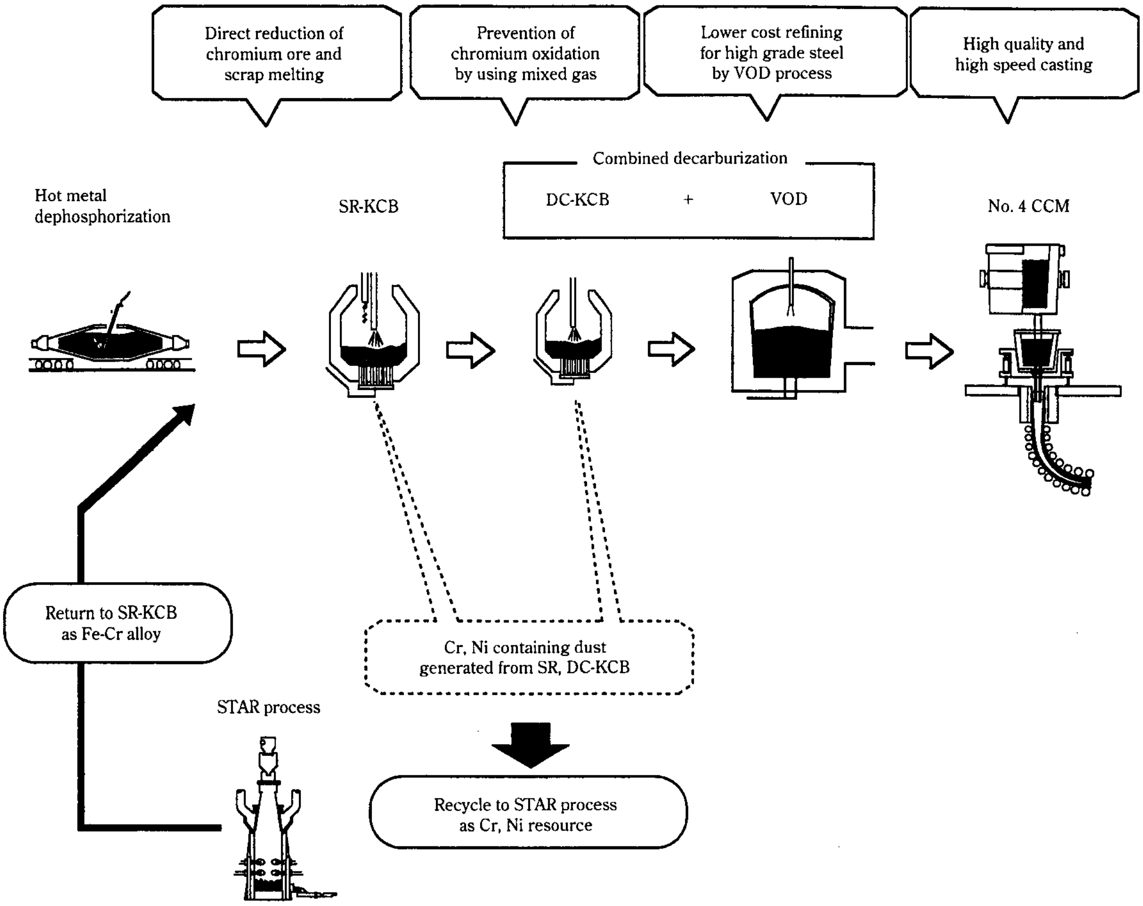


Fig. 2 Refining process of stainless steel in Chiba Works

tive increases and qualitative improvements in stainless steel, it is advantageous to develop a steelmaking process using blast furnace hot metal, which is suitable for mass production and can also be used to refine high quality stainless steel.

Kawasaki Steel began manufacturing stainless steel by the converter method in 1973, and undertook the development of a steelmaking technology for obtaining Cr, which is the main alloy element in stainless steel, by smelting reduction of Cr ore. The company also developed a high efficiency refining technology for high Cr, ultra-low C, N stainless steel with high corrosion resistance. The new Chiba Works No. 4 steelmaking shop was constructed in 1994, and the smelting reduction–decarburizing furnace–VOD–CC process shown in **Fig. 2** was completed, establishing a mass production technology for high quality stainless steel by the converter method.[3] The features of this refining process are summarized below.

(1) Smelting Reduction Process Using Cr Ore

Revolutionary steelmaking process which does not rely on expensive FeCr; raw Cr ore is reduced in the smelting reduction furnace (SR-KCB) and the product is used as a Cr source.[4]

(2) High Efficiency Production of Ultra-low Carbon Stainless Steel

High efficiency refining of high-Cr steel, which is difficult to decarburize and denitrize; features strongly-stirred bottom blowing using the high flow rate slit plug.

(3) Recycling Process which Eliminates Industrial Waste

Dust generated by the steelmaking shop is recovered and recycled as Ni, Cr, and other raw materials by smelting reduction in the STAR process (stainless advanced reactor) for treatment of stainless steel dust.

2.2 Hot Rolling, Annealing, and Pickling Processes

Because stainless steel has high hot deformation resistance and inferior hot workability, a Steckel mill or other type of exclusive-use hot rolling mill for stainless steel is frequently used, but because these facilities are reversing mills, they have the drawback of low productivity.

In 1978, Kawasaki Steel began rolling wide widths of stainless steel at Chiba Works using the tandem rolling mill, which is a high productivity mill normally used in hot rolling of carbon steel, and undertook the development of the optimum rolling technology for stainless

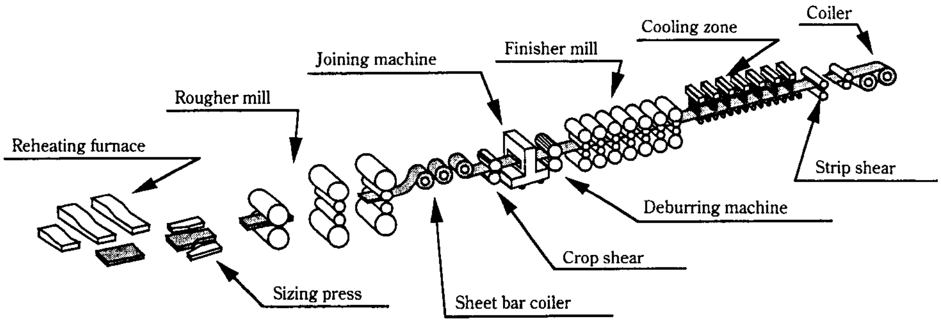


Fig. 3 Layout of No. 3 hot strip mill in Chiba Works

steel by tandem rolling. Thereafter, in 1995, the company began production at the newly constructed No. 3 hot strip mill, which made it possible to realize a hot rolling technology for developed stainless steels in an industrial process. **Figure 3** shows the layout of No. 3 hot strip mill.[5] In addition to width adjustment by the sizing press and improvement in rolling accuracy resulting from the mill's high rolling capacity, this line is making an important contribution to product quality control in stainless steel by enabling control of the rolling temperature, rolling pattern, and cooling.

3 Distinctive Stainless Steel Products in Respective Fields

3.1 Automotive Field

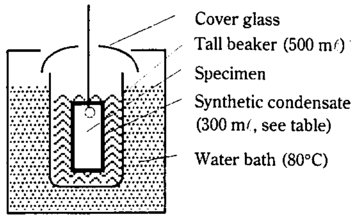
The quantity of stainless steel sheets used in the field of transportation equipment increased markedly from 28 000 t in 1975 to 106 000 t in 1995. Looking at the breakdown of applications, shipments for automotive applications account for the great majority, and have increased from 23 000 t to 84 000 t. The largest part of this, which is equivalent to approximately 1.5% of the car weight, consists of materials for use in exhaust system components, beginning with mufflers and converter shells. The main factors in this increase were efforts to cope with worsening of the corrosion environment in the exhaust system due to the use of the catalytic converter as a measure against pollution by exhaust gas and the extension of the guarantee period for exhaust system parts, which resulted in a changeover from hot-dip aluminum coated steel to stainless steel for virtually all exhaust system parts.[6] In parts of the automotive exhaust system, unlike general applications, priority is given to the essential functions of the material, such as corrosion resistance and heat resistance, rather than to appearance, and importance is also attached to reducing manufacturing costs by adopting stainless steel. To enable this changeover to stainless steel for auto exhaust system parts, Kawasaki Steel freed itself from the conventional manufacturing process for stainless steel, and instead developed a mass production system for auto exhaust system parts using cold rolling and annealing equipment for carbon steel, taking advantage of the company's superior position as a blast furnace steel maker.[7]

With regard to reverse rolling by the Sendzimir mill, which is an exclusive use mill for stainless steel, Kawasaki Steel realized continuous rolling by the high efficiency tandem mill for carbon steel in 1978. In finish annealing and pickling by exclusive use annealing and pickling facilities for stainless steel, high efficiency annealing and pickling of stainless steel were made possible by the development and application of a high efficiency electrolytic pickling method with the continuous annealing line for carbon steel in 1988. This cold rolling process is the optimum process for stainless steel products in which priority is given to function, as represented by materials for the automotive exhaust system, and was linked to the development of other products which can be used in a wide range of fields as tandem cold rolled functional products.

3.1.1 Muffler material

Hot-dip galvanized or aluminum coated steels had long been used as automotive muffler materials. However, when the three-way catalyst was introduced in response to exhaust gas regulations, which began in the latter half of the 1970s, the composition of the exhaust gas changed, and corrosion became more severe due to the condensates which form in the muffler. Kawasaki Steel developed the test shown in **Fig. 4** for evaluating muffler corrosion using a synthetic condensate and promoted the development of stainless steels for use in mufflers. At the same time, the company also established a mass production system for muffler materials by the tandem cold rolling manufacturing process for functional products, which include four steel grades from R409L to R436LT shown in **Table 1**.[8] Although the adoption of stainless steel in mufflers spread from SUH409L (ultra-low C, N + Ti 11%Cr), which is classed among the heat resistant steels, the adoption of stainless accelerated beginning in the second half of the 1980s as a response to the extension of muffler guarantee periods and a countermeasure for salt damage to

Procedure:
Specimen pre-oxidation in air at 400°C for 5 h.
Full immersion in synthetic condensate at 80°C
↓
Condensing at 80°C to completely dry
↓
Pouring of synthetic condensate
Repeat immersion-dry 10 cycles



(ppm)

Cl^-	SO_3^{2-}	SO_4^{2-}	CO_3^{2-}	NO_2^-	NO_3^-	CH_3COO^-	HCHO	$COOH^-$	NH_4^+	Activated carbon
250	1 250	1 250	2 000	100	20	400	250	100	2 500	50 g/ℓ

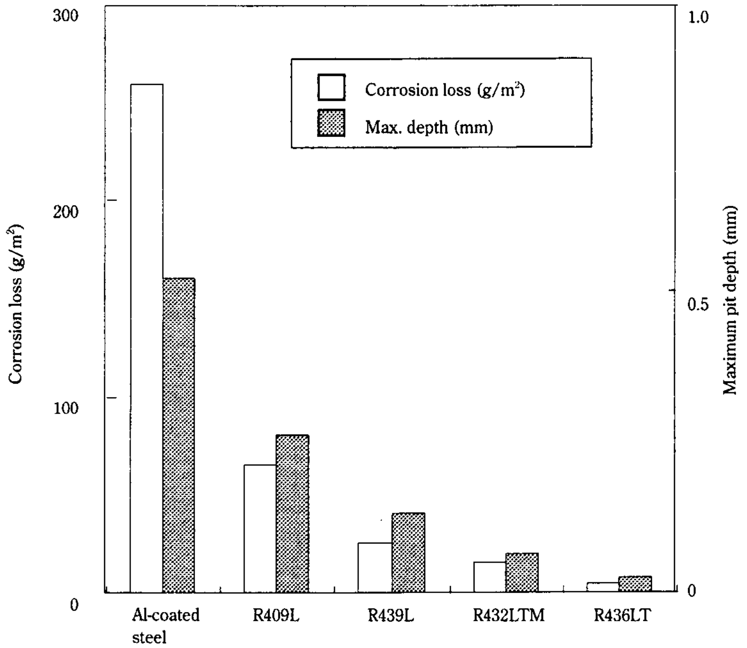


Fig. 4 Corrosion behavior of muffler grade steels in synthetic condensate corrosion test

Table 1 Stainless steels for automotive exhaust systems

(mass%)

Application	Standard designation		Typical example of main compositions								
	Kawasaki Steel Standard	JIS	C	Si	Mn	Cr	Mo	Nb	Ti	Al	La
Muffler	R409L	SUH409L	0.01	0.3	0.3	11.2	—	—	0.3	—	—
	R432LTM		0.01	0.1	0.2	17.5	0.5	—	0.3	—	—
	R436LT	SUS436L	0.01	0.1	0.2	17.8	1.2	—	0.3	—	—
Exhaust manifold	R429EX		0.01	0.9	0.4	14.8	—	0.45	—	—	—
	R430LNM	SUS436J1L	0.01	0.3	0.3	17.5	0.5	0.38	—	—	—
	R434LN2	SUS444	0.01	0.3	0.2	19.0	1.9	0.35	—	—	—
Metallic substrate of catalyst	R20-5USR		0.005	0.1	0.1	20.1	—	—	—	5.7	0.1

mufflers due to the salt for melting snow which is spread on roads in North America and elsewhere. At present, stainless steel, including R436LT, which offers the highest corrosion resistance, is used as required by the corrosiveness of the exhaust system, and stainless steel has been adopted for virtually 100% of mufflers. As a result, a large market for stainless steel was opened up in the new field of functional products.

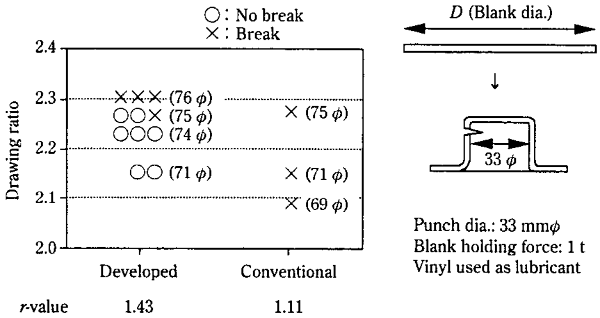


Fig. 5 Deep drawability of R429EX with increased r-value

3.1.2 Exhaust manifold material

In parallel with the adoption of stainless steel in mufflers, stainless steel has also been progressively adopted as a material for the upstream parts of the exhaust system, including the exhaust pipe and others. In these components, heat resistance is necessary because the temperature of the exhaust gas is increased by the use of the catalytic converter. For this reason, ultra-low C, N + Nb type steels, which possess both high corrosion resistance and high temperature strength, are used. The representative steel types manufactured by Kawasaki Steel are shown in Table 1.

In many cases, pipes for these applications are subjected to severe working, including bending and expanding. Kawasaki Steel manufactures high quality stainless steel electric welded tubes for processing as exhaust pipes by the CBR (chance-free bulge roll) forming method, which was developed at the company's Chita Works and generates little pipe forming strain.[9]

Recently, stainless steel has progressively replaced cast iron as a material for exhaust manifolds. As part of the effort to achieve zero emissions and low fuel consumption, various types of stainless steel manifolds have been developed, beginning with the combined catalytic converter type, simultaneously with a trend toward higher exhaust gas temperatures. For this reason, materials must provide excellent formability as well as high temperature characteristics. Ferritic stainless steel is inferior to the austenitic type in high temperature strength and formability, but has a low thermal expansion coefficient and is therefore used in exhaust manifold materials from the viewpoint of thermal fatigue. At present, the mainstream material has become 15Cr-Nb type R429EX, considering the balance of high temperature properties and formability. In particular, with R429EX, the r-value, which is an important index of formability, has been increased by approximately 30% while continuing to maintain heat resistance, resulting in improved deep drawability and hole expanding properties, as shown in **Fig. 5**.

3.1.3 Metal honeycomb material

In the catalytic converter, which is used as a countermeasure for auto exhaust gas purification, Pt, Rd, and other noble metal catalysts are held in a honeycomb type support. In supports made from stainless foil, the temperature of the catalysts rises quickly because the heat capacity of the foil is small, and consequently, the catalyst begins to function effectively almost as soon as the engine is started. Moreover, in comparison with the ceramic honeycomb, the stainless foil type also has other distinctive advantages, including a superior thermal shock property and, due to the small cross-sectional surface area of the holder itself, low resistance to the exhaust gas. In recent years, there have also been an increasing number of examples in which the converter is installed directly under the engine, and as a result, even more outstanding high temperatures properties have been demanded in the honeycomb holder, such as a required foil thickness of less than 50 μm.

In 1986, Kawasaki Steel developed R20-5SR as a steel for metal honeycombs.[10] This steel is based on 20%Cr-5%Al steel with a selective addition of La, which, among the rare earth metals, makes a particularly large contribution to oxidation resistance. As a further development of this product, in 1993, Kawasaki Steel developed R20-5USR, as shown in Table 1, by adding Zr, achieving the highest level of oxidation resistance among steels of this type.[11] At the same time, the company also developed a wide foil rolling technology, which made it possible to manufacture 30 μm honeycomb material with a width of 1 000 mm.

3.2 Architectural and Construction Materials

The amount of stainless steel sheets used in construction increased greatly from 26 000 t in 1975 to 157 000 t in 1995. In addition to the excellent corrosion resistance of stainless steel, another main factor in this dramatic growth is the fact that the diverse range of surface finishes which are possible with stainless steel, including the mirror finish, etching, color, and polishing, are particularly well suited for realizing design features in office building entrances and interiors. Stainless steel is also used on a large scale as a roofing and wall material for various types of large structures, beginning with gymnasiums and convention centers.

In particular, a waterproofing construction technique was developed for stainless steel roofs, and consequently, a considerable number of large scale roofs have been executed using bare stainless steel without additional coating. However, because corrosion resistance requirements vary greatly depending on the site environment, Kawasaki Steel carried out research on the atmospheric corrosion resistance of stainless steel, which resulted in the development of a number of ferritic stainless steels for use as construction materials.[12]

As construction materials, Kawasaki Steel developed

Table 2 Mechanical and physical properties of stainless steels for buildings

Steel	YS (N/mm²)	TS (N/mm²)	El (%)	λ (W/mK)	α (K^{-1})	d (g/cm³)
RSX-1	328	492	33	—	10.3×10^{-6}	7.75
R445MT	342	490	32	19.5	10.1×10^{-6}	7.68
R24-2	392	520	31	—	9.8×10^{-6}	7.66
R30-2	430	539	30	18.9	9.6×10^{-6}	7.64
SUS304	284	637	58	16.2	16.0×10^{-6}	7.93

λ: Thermal conductivity measured at 298 K
α: Coefficient of expansion at the temperature between 273 K and 573 K
d: Density

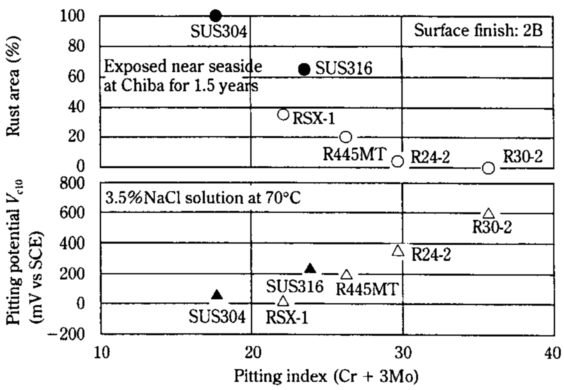


Fig. 6 Corrosion resistance of the developed ferritic stainless steels

the steel grades from RSX-1 to R30-2 (SUS447J1) in **Table 2**. Regarding the corrosion resistance of these products, their atmospheric corrosion resistance in atmospheric exposure tests is superior even to that of SUS316, as shown in **Fig. 6**. It might be noted that new JIS steel types (SUS445J1, J2) have been established for 22Cr steel, and further popularization of these products can therefore be expected in the future. Moreover, because ferritic stainless steels have a small thermal expansion coefficient in comparison with SUS304 and other austenitic stainless steels, thermal strain due to welding and temperature changes is also smaller, making the ferritic type advantageous for use in roofing materials. These are all high purity, high Cr type stainless steels. In particular, R30-2 (SUS447J1) offers the highest level of corrosion resistance and was therefore adopted for the roof of the Passenger Terminal of the New Kansai Airport, which is Japan's first offshore airport, and was also used as the material of the roof shown in **Photo 1** at the Naha Airport, which is considered to have an even more severe corrosion environment. Because a non-glare appearance is an essential requirement for airport roofs, a dull finish (Silver Soft) was developed by creating minute irregularities, as shown in **Photo 2**. This finish has also been highly evaluated as a

Photo 1 An aerial view of the passenger terminal building at Naha Airport: the building roofed with SUS447J1

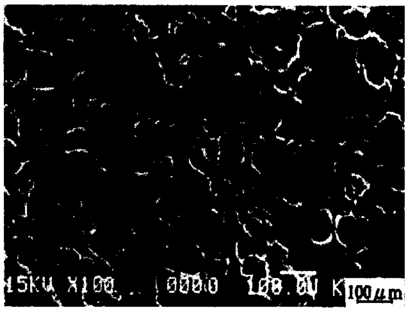


Photo 2 Surface of dull finish "Silver Soft" observed by SEM

design-quality stainless steel.[13)]

Recent years have also seen continuing increases in the adoption of stainless steel in the field of civil engineering, beginning with water pipe bridges, balustrades, dams, and estuary weirs, and civil applications are now expected to become the largest new demand field for stainless steel.[14)] As one example, **Photo 3** shows an expand metal honeycomb frame, which is used in environment-friendly revetment works to create natural rivers.[15)] The material is the 18Cr-1.2Mo ferritic stainless steel R436LT with high corrosion resistance.

3.3 Household and Business Machine Use

The amount of stainless steel sheets used in these fields increased from 126 000 t in 1975 to 204 000 t in 1995, but conversely, the share of total stainless steel consumption declined from 17% to 12%. However, as fields for stainless steel, applications include familiar items such as cooking utensils and kitchen products, and their importance remains unchanged. With the exception of commercial kitchens, general purpose SUS304 is still overwhelmingly used, but to win wider popularity for ferritic stainless steels, which are inexpensive in com-

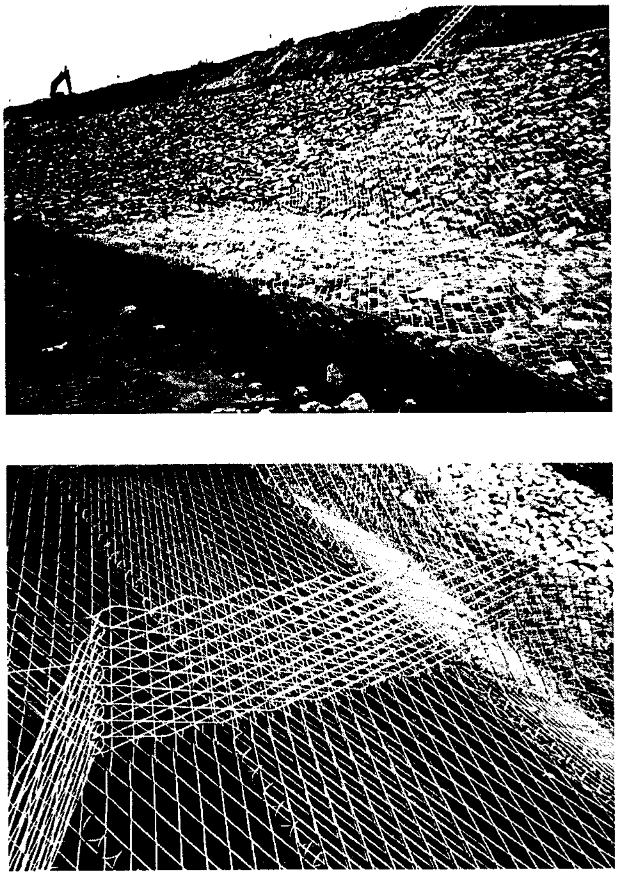


Photo 3 Expand metal honeycomb frame used for revetment works

parison with the austenitic type, Kawasaki Steel is endeavoring to improve the deep drawability and other formability properties of the ferritic type. The deep drawing property of ferritic stainless steel is largely dependent on the r-value, which depends on the crystalline textures which are formed in the hot rolling and cold rolling processes. SUS430LX, which is manufactured by adding either Ti or Nb to ultra-low C, N steel, is an outstanding steel grade in this respect. A basically sufficient deep drawing property for practical applications can be imparted to this product, but the stripe pattern called "ridging" occurs when deep drawing is performed with this steel. Thus, even though it is possible to form the desired product, it has the drawback of impaired appearance. This means that a large amount of grinding is required for use in familiar everyday objects and has been an obstacle to popularization. Together with elucidating the mechanism of ridging, Kawasaki Steel also developed R430UD, which belongs to the class of SUS430 steels, and R430XT, which is classed as SUS430LX, as ferritic stainless steels which alleviate ridging. As one example, **Photo 4** shows the improvement in the grain colony bands which are the root cause of ridging, comparing R430UD and SUS430.[16] **Photo 5** shows the results of photographic observation of ridging after deep drawing with these steels.

Although importance has generally been attached to beauty and corrosion resistance in stainless steel products, anti-microbial products have been developed in many everyday products in recent years, and consequently, the anti-microbial property was also demanded even in stainless steel products. Kawasaki Steel developed an antimicrobial stainless steel using Ag, which has a high anti-microbial effect, for the first time,[17] and the steels R430AB and R430LXAB, which are based on the two grades SUS430 and SUS430LX, are now being used in baskets for washing machines and in food storage lockers. Unlike surface treatments for securing the anti-microbial property, it is a distinctive feature of these steels that the anti-microbial property exists in the material itself, and can therefore be obtained even after grinding and similar processing. Thus, these steels have a wide range of applications, including products with a polishing or mirror surface. **Table 3** shows the results of a test of the anti-microbial property. Because stainless steel products are used in a variety of applications, surface properties other than the anti-microbial property, corresponding to the application, are also expected in the future.

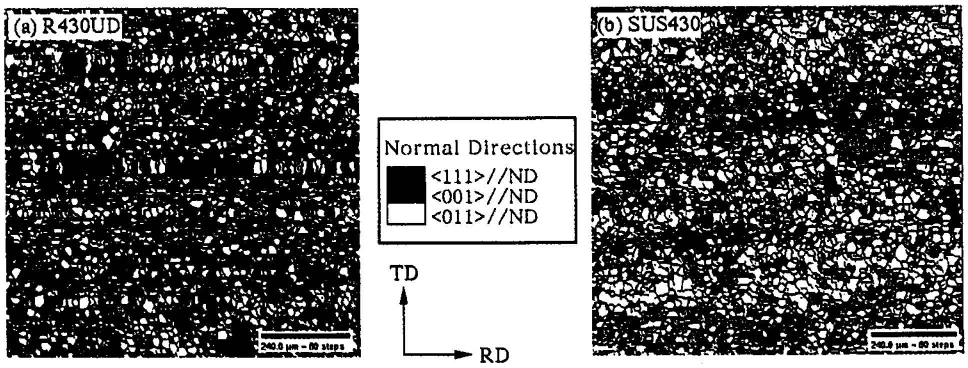


Photo 4 Texture maps for normal direction, tolerance angle = 15°, of the 1/4 thickness ND plane of samples (a) R430UD and (b) SUS430

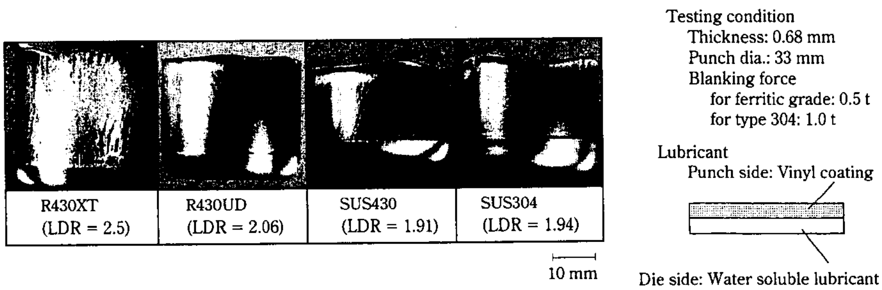


Photo 5 Appearance of ridging and drawn cup-height of R430UD and R430XT after Olsen cup test

Table 3 Results of antimicrobial activity test in samples after polishing for 1 μm

Sample	Finish	Species	Viable cell count before test (cfu/sample)	Viable cell count after 24 h (cfu/sample)	Rate of cell reduction (%)
R430LN-AB	BA ↓ #600	*Escherichia coli*	3.1×10^5	8.0×10	>99
		Staphylococcus aureus	3.9×10^5	5.0×10	>99
SUS430LX (Control)	2B	*Escherichia coli*	3.1×10^5	4.0×10^6	
		Staphylococcus aureus	3.9×10^5	5.4×10^5	

Testing facility: Japan Food Hygiene Association
Date of test certificates: Jan. 19, 1998
Nos. of test certificates: No. 71-8289, No. 71-8290

4 Conclusion

Stainless steel possesses the distinctive features of outstanding corrosion resistance and beauty. It has been widely adopted in a large number of products and is continuing to enjoy quantitative growth.

Kawasaki Steel has constructed the advanced production system particularly for ferritic stainless steels, and has devoted great efforts to developing a considerable number of new products with the aim of popularizing the ferritic type. These include functional products, represented by materials for the automotive exhaust system, high corrosion resistance stainless steels, represented by SUS447J1, stainless steels with high temperature oxidation resistance, such as R20-5USR, ferritic stainless steels with excellent deep drawability, and others. The company is promoting the development of new applications based on this wide range of ferritic stainless steels, and hopes thereby to contribute to the further popularization of stainless steel.

References

1) Japan Stainless Steel Association: "Statistic Chronological Table of Stainless Steel Sheet for Amount of Order Intakes by Use"
2) T. Kawasaki: *Kawasaki Steel Giho*, **30**(1998)2, 69–77
3) Y. Nabeshima, S. Ogura, and S. Yamada: *Kawasaki Steel Giho*, **28**(1996)4, 206–212
4) Y. Kishimoto, K. Taoka, and H. Takeuchi: *Kawasaki Steel Giho*, **28**(1996)4, 213–218
5) T. Imae, N. Nomura, and S. Miyoshi: *Kawasaki Steel Giho*, **28**(1996)4, 219–223
6) N. Matsuura: Report of International Stainless Steel Forum Market Development Committee
7) M. Kobayashi, T. Kawasaki, Y. Mihara, H. Satoh, M. Takada, and F. Yanagishima: *Kawasaki Steel Giho*, **20**(1988)1, 20–26
8) S. Satoh, T. Ujiro, and K. Ishii: *Kawasaki Steel Giho*, **31**(1999)1, 28–33
9) T. Toyooka, Y. Hashimoto, K. Kobayashi, S. Itadani, T. Ide, and Y. Nishida: *Kawasaki Steel Giho*, **22**(1990)4, 236–244
10) K. Ishii and T. Kawasaki: *J. Jpn. Inst. Metals*, **56**(1992)7, 854–862
11) H. Shimizu, M. Kono, and K. Yoshioka: *Kawasaki Steel Giho*, **25**(1993)2, 119–123
12) Y. Yazawa, K. Yoshioka, and H. Togashi: *Kawasaki Steel Giho*, **25**(1993)2, 131–137
13) Y. Oka and N. Kuriyama: *Kawasaki Steel Giho*, **30**(1998)2, 118–120
14) International Stainless Steel Forum Market Development Committee: Report of 5th Expert Meeting, (1999)
15) Japan Stainless steel Association: *Stainless*, **44**(2000)1, 4–10
16) T. Yokota, M. Brochu, and S. Satoh: *Kawasaki Steel Giho*, **30**(1998)2, 115–117
17) T. Yokota, M. Tochihara, and M. Kobayashi: *Kawasaki Steel Giho*, **30**(1998)2, 121-122