NIPPON STEEL TECHNICAL REPORT No. 129 MARCH 2023

*Technical Review*

# Coated Steel Sheets and Related Technologies to Realize a Comfortable Life by Being Environmentally-friendly, and to Meet Social Needs Such as National Resilience and Countermeasures for Aging Infrastructure

Fumiaki NAKAMURA* Keitoshi HARUTA

## Abstract

***For flat-rolled steel products used for home appliances and construction, coated steel sheets have been actively developed to improve their performance. In recent years, it has become necessary not only to have excellent performance, but also to realize a comfortable life by being environment-friendly, and to meet social needs such as national resilience and countermeasures for aging infrastructures. The performance of coated steel sheets has also diversified according to their purposes, and not only steel sheets, but also steel sheet utilization technologies have been developed in various ways. Through a wide range of technological developments, we will contribute to society by proposing values suitable for Japan, which is a mature and advanced country.***

## 1. Introduction

Coated steel sheets have been widely used as steel sheet products for home appliances and building materials. Particularly, since 2000, Nippon Steel Corporation has developed and commercialized highly corrosion resistant Zn-Al-Mg-Si coated steel sheets (SuperDyma™[1] and ZAM™[2, 3]) by coating hot-dip galvanized steel sheets with Mg and Si as well as Al to meet corrosion resistance needs in rust-prone environments such as home appliances and building materials.

In the building materials field, it is often the same persons that determine the specifications and pay the maintenance costs of the equipment. Investment in the equipment often depends on the total amount of the initial investment and the maintenance cost. The durability performance of the equipment is also important and has a large impact on its maintenance cost. It is therefore paramount that the equipment has higher corrosion resistance. In addition, building national resilience is required in circumstances where there is a higher risk of natural disasters due to climate change and other environmental challenges. We are also faced with the advancing deterioration of public infrastructure constructed during the high economic growth period. These situations create the demand for materials with low cost and excellent durability, and thus the need for high corrosion resistance. The increasing sophistication of industrial design has also increased the opportunities for prominent designers to create beautiful and unique exteriors in the field of building materials. These opportunities are regarded as new attempts to accept designability as a value.

In the home appliance field, beautiful appearances have been traditionally demanded in addition to the high corrosion resistance. Accordingly, coated steel sheets like ZINKOTE™ and VIEWKOTE™ have been widely used. However, increasing diversification of home appliance products in recent years has increased the opportunities that demand functions other than beautiful appearance, unique design, and high corrosion resistance.

In terms of environmental friendliness, the home appliance field has taken the lead by restricting the use of environmental impact substances as the global standard under the RoHS Directive. This trend has prompted the standardization of chromate-free coatings. As environmental awareness has increased also in the building material field, the Japanese Industrial Standards Committee (JISC) has moved to standardize chromate-free coatings. Three Japanese Industrial Standards, or hot-dip 55% aluminum-zinc alloy coatings (JIS G 3321),[4] electrogalvanized coatings (JIS G 3313),[5] and hot-dip alu-

* General Manager, Flat Products Technical Service & Solution Dept., Flat Products Marketing Div., Flat Products Unit
2-6-1 Marunouchi, Chiyoda-ku, Tokyo 100-8071

minum coatings (JIS G 3314), are already specified as chromate free. The remaining three types of zinc coatings, or hot-dip galvanized coatings (JIS G 3302), hot-dip zinc-aluminum-magnesium alloy coatings (JIS G 3323), and hot-dip zinc-5% aluminum alloy coatings (JIS G 3317), are specified to become chromate free on the next revision.

Infrastructure facilities built by using products with excellent durability will lead to a reduction in the amount of steel used in the long term because their obsolescence replacement cycle will be extended. In the current global trend for carbon neutral, Nippon Steel's highly corrosion resistant coated steel sheets are expected to help reduce $CO_2$ emissions thanks to their excellent durability performance. Their effectiveness is very important and their commercial value can be improved in the future. At that time, we believe that compliance with restrictions on the content of environmentally hazardous substances in the products themselves will also contribute to improving their commercial value.

As a result of enthusiastically promoting the improvement of corrosion resistance and the research and development of new designs and functions to adapt to the evolution and diversification of market needs, Nippon Steel has advocated its coated steel sheet products with various added values as measures for achieving environmentally friendly and comfortable lives, making the nation resilient, and countering the obsolescence of infrastructure. Specifically, Nippon Steel has developed new highly corrosion resistant coated steel sheets ZEXEED™,[6] coated steel sheets SGL™ for building materials, steel sheets SuperDyma™ Crystal and chromate-free galvanized steel sheets with spangle texture, chromate-free hot-dip galvanized steel sheets FeLuce™, functional VIEWKOTE™, and antivirus steel sheets. Nippon Steel has also developed technologies that promote the usage of its coated steel products to maximize their performance, including improvement solutions for cut edge corrosion resistance and the "Katachi" Solution. Below we introduce the backgrounds and circumstances of our development activities and the positioning of our products as product strategies and technology prospects.

## 2. Main Subjects

### 2.1 Nippon Steel's highly corrosion resistant Zn-Al-Mg-Si coated steel sheet series

Nippon Steel has SuperDyma™ and ZAM™ as representative highly corrosion resistant Zn-Al-Mg-Si coated steel sheets. We also offer an extensive menu of coated steel sheets by microalloying with Mg. Nippon Steel's highly corrosion resistant Zn-Al-Mg-Si coated steel sheet series is introduced below. Each product has not only improved corrosion resistance, but also properties optimized to meet specific applications.

The development of zinc coatings has a long history. In 2000, we developed the SuperDyma™ and ZAM™ highly corrosion resistant steel sheets with about 11% Al, about 3% Mg, and a small amount of Si added to the zinc base. Here we describe the zinc coated steel sheet products we have developed since then.

#### 2.1.1 New highly corrosion resistant galvanized steel sheets ZEXEED™

Both SuperDyma™ and ZAM™ are highly corrosion resistant zinc alloy-coated steel sheets classified under JIS G 3323. Al, Mg, Si, and other elements are added to the conventional zinc coating, which enhance the corrosion resistance by the combined effect of alloying elements. In addition to the elution rate of the coating itself being low even in a severely corrosive environment, the corrosion products formed are denser than those formed on conventional coatings and act as protective films that do not easily allow moisture and air to enter inside. They consequently retard the progress of corrosion and provide corrosion resistance not only in flat regions, but also in cut edges and formed regions. The Mg contained in the coating is one major reason why the Zn-Al-Mg-Si coated steel sheets have high corrosion resistance. Particularly, the building material field had a strong need for high corrosion resistance and required steel sheets with excellent durability. However, the maximum amount of Mg added to the coating composition was initially 2 to 5% and no technologies were established to add more Mg. Thus, SuperDyma™ and ZAM™, originally developed by different companies, contained approximately the same amount of Mg. Nippon Steel then established a technology to add more than 5% Mg to the coating and developed and commercialized ZEXEED™ with improved corrosion resistance to meet the needs for even higher corrosion resistance.

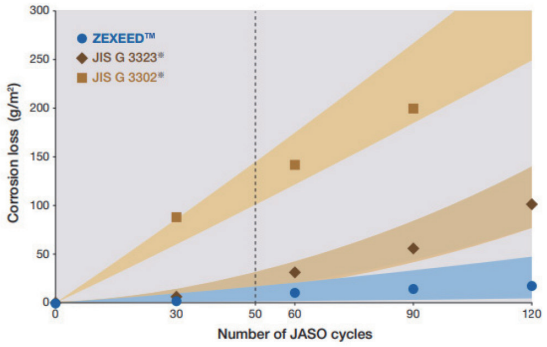


**Fig. 1 Change in corrosion loss of each plated steel in the JASO test**

Increased ratios of Al and Mg in the ZEXEED™ coating reduced the elution rate of the coating itself as compared with SuperDyma™ and ZAM™. Moreover, its protective film was denser and less likely to allow moisture to permeate. These factors combined to improve the corrosion resistance of ZEXEED™. Particularly, breaking the 2 to 5% wall of the Mg content allowed Mg to be added in excess of 5%. As a result of optimizing the Mg content in consideration of the balance of formability and other product properties, we finally selected a Mg content of 6%. **Figure 1** shows the changes in the corrosion weight loss of coated steel sheets in their JASO combined cyclic corrosion test.

The JASO 50 cycle corrosion weight loss shows that ZEXEED™ has more than 10 times corrosion resistance than that of hot-dip galvanized coatings and more than two times that of SuperDyma™ and ZAM™. (One JASO test cycle consists of 2 h of salt spray, 4 h of drying, 2 h of wetting, or lasts a total of 8 h. It is said that 50 cycles are generally equivalent to about 17 y in a rural environment and 5 y in a salt damage environment.)

Another notable feature of ZEXEED™ is that it exhibits excellent corrosion resistance performance even in a running water environment and a water dripping environment where the conventional SuperDyma™ and ZAM™ were not resistant enough. **Figure 2** shows the corrosion resistance data of ZEXEED™ in a dripping water environment.

#### 2.1.2 Prepainted steel sheets SGL™ for building materials

The roof wall members of houses and buildings are thin and their designability is important. Galvalume steel sheets or hot-dip

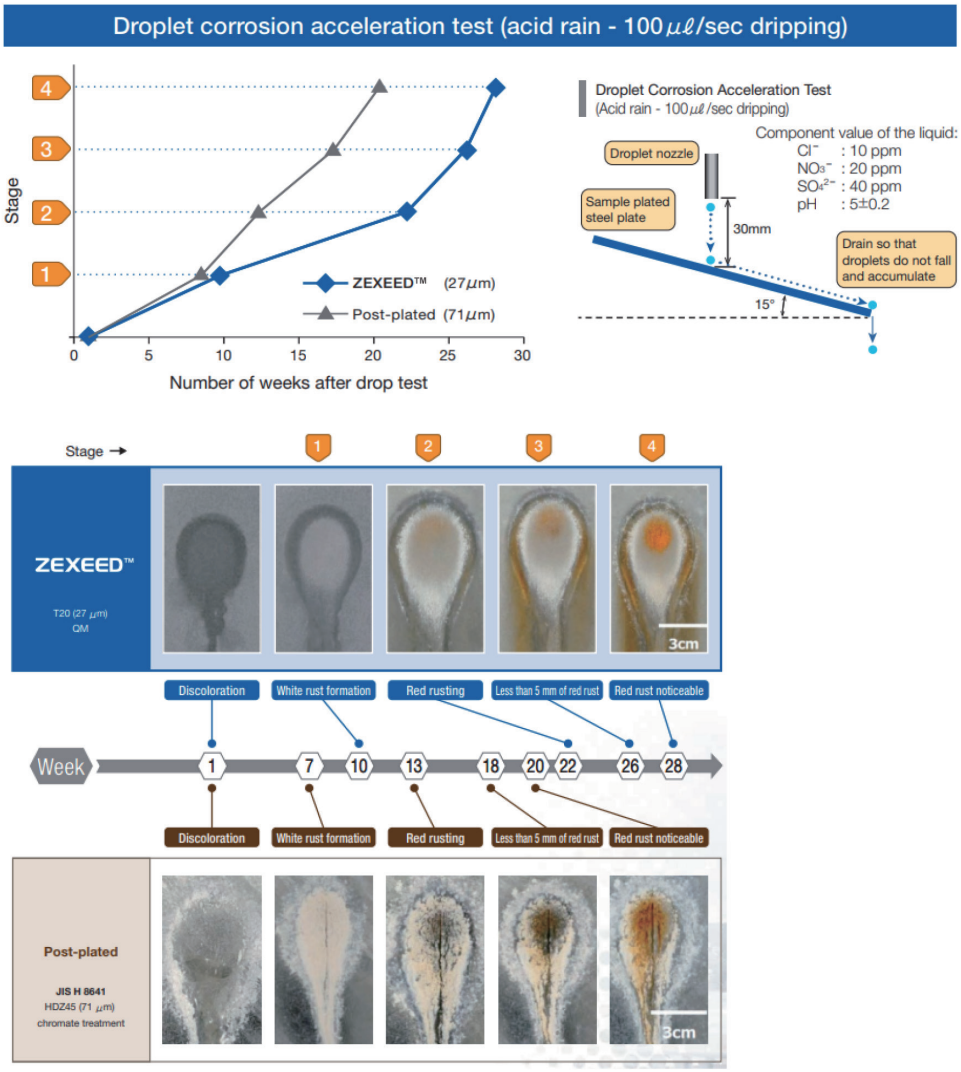


**Fig. 2 Corrosion resistance in a droplet-forming environment**

55% Al-zinc alloy coated steel sheets and prepainted Galvalume steel sheets have been traditionally used as standard roof wall materials on many houses and buildings. Nippon Steel introduced the technology of Galvalume Steel Sheet™ from the Bethlehem Steel Corporation of the USA for the first time in Japan and registered its trademark. The patent for this technology was then sold to BlueScope Steel Limited of Australia. As the patent expired in 2000, steelmakers around the world began to produce similar products and rapidly commodified Galvalume steel sheets. To circumvent this situation, Nippon Steel Coated Sheet Corporation, a member of the Nippon Steel Group, commercialized SGL™ as a differentiated product by adding Mg to the Galvalume coating to improve corrosion resistance.

SGL™ has Mg added to the base of the hot-dip 55% aluminum-zinc alloy coating. It thereby exhibits extremely excellent corrosion resistance in terms of the flat surface corrosion resistance required of exterior steel materials (**Fig. 3**).

According to the Housing Quality Assurance Act, exterior steel members are customarily required to guarantee the number of years to perforation in the roof wall field. The perforation warranty period for roofs constructed of Galvalume steel sheets was generally 10 y.

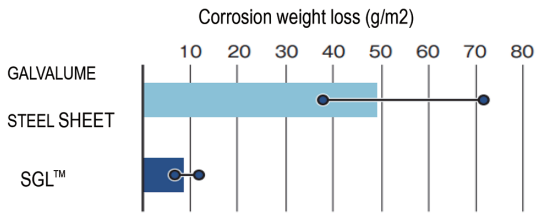


**Fig. 3 Corrosion resistance of SGL™ and GL by combined cyclic corrosion test**

The perforation warranty period for roofs constructed of prepainted SGL™ coated steel sheets varies with conditions but it is generally extended to about 25 y for greater differentiation.

SGL™ was jointly developed by Nippon Steel, Nippon Steel Coated Sheet, and BlueScope Steel of Australia. It is manufactured and sold in the ASEAN countries by a joint venture established by the three companies. The technology of adding Mg to the zinc alloy coating is used to improve corrosion resistance as conducted for ZEXEED™, SuperDyma™, and ZAM™. In addition to perforation corrosion resistance, white rust resistance is required of exterior

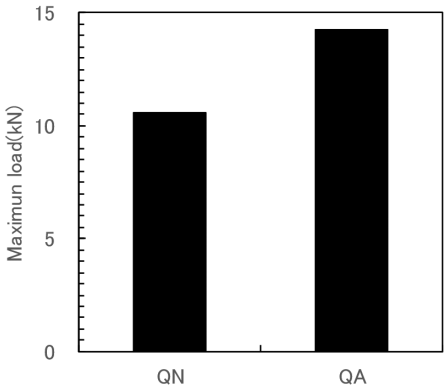


**Fig. 4 Results of bonding strength by tensile shear test**

steel sheets so as not to mar the appearance during their use. The Mg content of the SGL™ coating is optimized and is different from that of ZEXEED™, SuperDyma™, and ZAM™. Furthermore, SGL™ steel sheets and prepainted SGL™ steel sheets are compliant with JIS G 3321 and JIS G 3322, and are widely used in Japan.

**2.1.3 SuperDyma™ steel sheets with excellent bonding strength**

There are increasing needs for joining methods other than welding in the construction and civil engineering fields due to the occurrence of serious problems such as welding defects in bridge pier steel plate jackets and bridge fall prevention devices on the Metropolitan Expressways in the Greater Tokyo Area.

In the road and railway fields, structures built during the high economic growth period have now reached 50 y since their construction and are faced with urgent needs for life prolonging measures. In these renewal works, it is necessary to minimize the functional outage of infrastructure. It is thus desirable to adopt new methods of repair and reinforcement rather than to scrap and build. There are increasing needs for improving durability and constructability and for reducing costs throughout the material, product, and construction stages.

To meet these needs, we developed a chromate-free coating QA with excellent bonding strength (**Fig. 4**).

An example of effective use of adhesive bonding is the adhesive bonding method used in the repair works on Shinkansen viaducts. This is one of the standard methods adopted in repair works. SuperDyma™ steel sheets are also expected to find greater applications in the fabrication of enclosures and boxes to improve working efficiency and to reduce the generation of fumes during welding.

**2.2 Coated steel sheets designed to take advantage of coating substrate appearance**

In the past, prepainted steel sheets were a typical example of designed steel sheets and were covered with a uniform pattern or made to appear uniformly. In recent years, there have been cases where the uneven appearance of the coating substrate is regarded as a new design. Designed steel sheet products developed by utilizing the appearance of the coating substrate are introduced below.

**2.2.1 SuperDyma™ Crystal**

In the highly corrosion resistant galvanized steel sheet markets in East Asia, the shares of SuperDyma™ have been eroded by similar products with lower prices or dubiously guaranteed longer service lives, especially for solar panel mount applications. To ensure

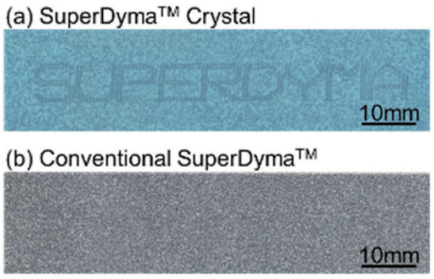


**Photo 1 Appearance of SuperDyma™ Crystal**

the continuous and confident use of solar power generation, we think it is important to show to the fabricators and owners of solar panel mounts that our proprietary SuperDyma™ steel sheets can guarantee the corrosion resistance performance of such mounts with solid evidence. Amid a global carbon neutrality trend, the demand for solar panel mounts is increasing explosively. To distinguish SuperDyma™ steel sheets from their imitation products and secure their commercial value, we established the technology that allows characters to emerge like watermark characters and developed SuperDyma™ Crystal (**Photo 1**). This technology used the coating structure controlling technology that locally creates strongly and weakly shiny regions in the SuperDyma™ coating crystals. The point is that unlike conventional inkjet printing, it is possible to create characters that cannot be added afterwards. In addition, the technology is combined with easy-to-understand blue post-treatment to strengthen the SuperDyma™ brand.

**2.2.2 Chromate-free galvanized steel sheets with spangle texture**

In the air conditioning duct field, 6 feet wide galvanized steel sheets have been used from the viewpoint of duct fabrication efficiency. More specifically, regular spangle-finished galvanized steel sheets have been used so that it is easy to identify that they are zinc coated. Particularly, the appearance of the regular spangle finish not only identifies them as coated steel sheets, but also there are many people in the air conditioning duct industry who have a strong attachment to “regular spangles when it comes to ducts.”

Ducts were generally hidden by ceiling panels and used in places where they were not visible to equipment users after completion. In recent years, spangle patterns on galvanized steel sheets are now regarded as designed patterns and galvanized steel sheets have been installed exposed to view after completion in interior designs without ceiling panels. The size and shape of the spangle crystals are not exactly uniform and the spangles appear with subtle irregularities. There are increasing examples of interior designs that treat such irregularities as more radical design patterns.

As mentioned at the beginning, chromate-free galvanized steel sheets are being increasingly used to achieve environmental compliance in the building material field. It was difficult to ensure corrosion resistance with chromate-free regular spangle galvanized steel sheets. Achieving both a chromate-free coating and a regular spangle finish at the same time has been a major hurdle to the promotion of chromate-free galvanized steel sheets. Nippon Steel has optimized the regular spangle manufacturing method and the chromate-free coating type. The outcome is the regular spangle finish and chromate-free galvanized steel sheets with required corrosion resistance (**Photo 2**).

Our chromate-free galvanized steel sheets with spangle texture can meet both the preference of the duct industry for the spangle ap-

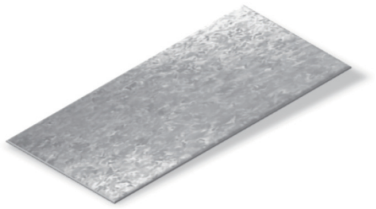

**Photo 2 Appearance of spangled hot dip galvanized steel sheet**


**Photo 3 Appearance of FeLuce™**

pearance and the challenge of the duct industry to make architectural designs, while considering the environment.

#### 2.2.3 FeLuce™

The hairline-finished electroplated steel sheet FeLuce™ is a new highly designed steel sheet developed to produce metallic brilliance by a new method of directly hairlining the corrosion resistant metal coating (**Photo 3**). The development of FeLuce™ faced the challenges of both maintaining corrosion resistance and expressing designability at the same time by grinding the coated surface and of both adding such functions as chemical resistance and fingerprint resistance by applying a resin film and maintaining the designability expressed on the coating surface simultaneously. For the former objective, we selected the optimum coating type and optimized the grinding conditions. For the latter, we developed a new thin resin coat and adjusted the painting conditions. In this way, we succeeded in commercializing FeLuce™. In the manufacturing process, hairlining equipment was introduced onto an existing electroplating line to complete the production of FeLuce™ only by the electroplating line. We were awarded the Good Design Award 2020 for FeLuce™ in recognition not only of our development of the highly designed steel sheet FeLuce™, but also for taking on the challenge of eco-friendly and lean manufacturing. FeLuce™ is expected to be used for home appliances, industrial equipment, steel furniture, and interior building materials, among other applications. We are pushing ahead to create new demand for FeLuce™ in two standard colors: high-quality and calming black and richly reflecting and interior space fitting silver.

### 2.3 Highly functional designed steel sheets

Conventionally designed steel sheets were generally evaluated by the indexes of how uniform and beautiful the sheet appears and of how long the beauty of the sheet lasts. In recent years, there have arisen needs for such additional functions as formability, corrosion resistance, stain resistance, and scratch resistance. With the spread of infectious diseases, the need for antivirus functions of the steel surface has developed. Our designed steel sheets with functions to meet such various needs are introduced below.

#### 2.3.1 Functional VIEWKOTE™

The prepainted steel sheet VIEWKOTE™ offers such advantages as elimination of degreasing and painting by customers and reduced use of volatile organic compounds (VOCs). Thanks to these benefits, VIEWKOTE™ is used in many applications, mainly home appliances. The performance requirements of customers, such as formability, corrosion resistance, stain resistance, and scratch resistance, vary widely with the use environments and applications. We have been developing a wide variety of functional VIEWKOTE™ products to meet these customer requirements. Take examples of air conditioner outdoor units and water heater housing outer panels. These applications require high formability and coating film design with excellent cut edge red rust resistance[7]. Because the contamination of the housing panels becomes more noticeable outdoors, there is also a need for adding stain resistance[7]. There is also a problem that scratches made during forming and transportation are easily visible. The adoption of VIEWKOTE™ was expanded by the development of orange-peel surfaced VIEWKOTE™[8] with surface irregularities precisely controlled. In recent years, the application of highly corrosion resistant SuperDyma™ as base steel has contributed to extending the product life and reducing the total cost.

We are also developing VIEWKOTE™ with such additional functions as oil and water repellency required in food ranges and other applications, thermochromism whereby temperature change can be visualized, and retroreflective paints to provide excellent visibility under light irradiation. We would like to propose new commercial values not obtainable with conventional prepainted steel sheets.

#### 2.3.2 Antivirus steel sheets

The antivirus steel sheets developed by Nippon Steel make use of titanium oxide known as a photocatalyst. Titanium oxide decomposes oxygen and water in the air by light energy and generates active oxygen. This active oxygen suppresses the propagation of viruses by its strong oxidizing action and displays an antiviral function. Antibacterial, deodorizing, and antiallergic functions can be additionally expected. The antivirus steel sheets are existing coated steel sheets to which the photocatalytic function is imparted. New properties such as designability, corrosion resistance, and fingerprint resistance can be obtained in addition to such performance properties of the coated steel sheets. The antivirus steel sheets are provided with a hybrid antivirus function that proves effective even in low light of about 500 lx and in dark places. They also have excellent formability. When the antivirus steel sheets are deep drawn, the photocatalytic layer does not peel and can retain its functions after deep drawing.

The antivirus steel sheets are supposed to be used in products that can be touched by many unspecified persons and in environments where droplets are scattered. We are now proposing use of our antivirus steel sheets to our customers.

### 2.4 Chromate-free hot-dip galvanized steel sheets

Recent years have seen increasing needs for environmentally friendly products in the building material field as in the home appli-

ance field. As mentioned above, the JIS standards for galvanized steel sheets clearly state that such sheets will be specified as chromate free at the time of the next revision.

### 2.5 Solutions for improving cut edge corrosion resistance

As mentioned above, corrosion products formed on the surfaces of ZEXEED™, SuperDyma™, and ZAM™ are dense and impermeable to moisture and air. They act as dense protective films, are highly effective in suppressing the progress of corrosion, and demonstrate high corrosion resistance not only on flat surfaces, but also on cut edges and formed regions. This is due to the effect that the corrosion products formed on the coated surface wrap around the cut edges when the coated steel sheets are used for a long period of time. Immediately after shearing, however, it is inevitable that red rust will form on the cut edges. This problem was difficult to solve by the surface coating technology alone. We investigated the technology of physically wrapping the coating components around the cut edges when the steel sheets are sheared. We obtained good results with two technologies, or the inclined edge shearing technology and the technology of shearing steel sheets with cut edges protected from corrosion. We expect these technologies to be implemented soon.

### 2.6 “Katachi” Solution

If we solve the structural problems of steel sheets related to buckling and local deformation, we can enjoy their shape benefits. We have evaluated the torsion of members with a large width to thickness ratio, conducted the research and development of buckling design technology, and focused on the practical application of members that have a rational cross-sectional shape and have both good structural and constructional performance. Furthermore, we have expanded the application of these design technologies to various fields such as housing structures, home appliances, and office automation equipment. These initiatives are collectively called the “Katachi” Solution (Katachi is “shape” in Japanese) because they focus on shapes and provide solutions for the use of steel materials.

The “Katachi” Solution utilizes computer simulation and computer-aided engineering (CAE) to analyze the mechanisms whereby structures deform and develop strength, and presents concrete improvement measures and quantitative effects.

## 3. Conclusions

Coated steel sheets for home appliances and building materials and their utilization technologies have significantly progressed and diversified in recent years. Major differences from the past are that coated steel sheet manufacturers compete not just for superiority or inferiority according to a single index, but also to how cheaply they can manufacture coated steel sheets while satisfying established standards. They also propose new values by themselves to create the values of end products, and develop technologies that facilitate the lives of consumers who use end products with heightened values. These technologies lead to proposals for the creation of an environmentally friendly society. Since not only product manufacturers, but also material manufacturers can propose the values of end products in the home appliance and building material fields, Nippon Steel’s advanced technologies can contribute to society. As a mature developed country, Japan needs companies that can make such proposals. It is important to conduct not only development in the research department, but also carry out development by accumulating information on the usage of steel by society and consumers and by grasping customer and society trends.

In this report we have focused on the various technologies introduced above. In the spirit of further advancement of such technologies, we will continue to propose new values and contribute to our society.

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Fumiaki NAKAMURA
General Manager
Flat Products Technical Service & Solution Dept.
Flat Products Marketing Div.
Flat Products Unit
2-6-1 Marunouchi, Chiyoda-ku, Tokyo 100-8071

Keitoshi HARUTA
General Manager
Flat Products Technical Service & Solution Dept.
Flat Products Marketing Div.
Flat Products Unit