

Steel Sheet for the Better Human Life (Application for Household Electrical Appliances, OA Equipment)

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1. Introduction

Our life has become increasingly comfortable thanks to the most advanced, high-performance electric home appliances and office automation (OA) equipment. **Fig. 1** shows the changes in ownership of major consumer durables per 100 households.¹⁾ Refrigerators, washing machines and black & white TVs, which made their debut as the “three essential status symbols” in the 1950s, were owned by almost all households in the 1970s. Since the 1970s, the so-called 3Cs—coolers (air conditioners), color TVs and cars—have become widespread. Today, the average household owns more than two air conditioners and more than two color TVs. In the decade from the mid-1990s, personal computer (PC) ownership spread markedly. Since around 2000, digital consumer electronics have become popular and DVD players, flat-panel TVs with liquid crystal or plasma displays, etc. have been spreading rapidly. Owing to those products, our lifestyles have changed dramatically.

In the field of home appliances, steel is used abundantly for exteriors, chasses, panels, and motor parts, etc. For example, looking at the material compositions of various home appliances recycled in 2009, the weight percentage of steel is 47% for flat-panel TVs, 56% for refrigerators, 53% for washing machines and 32% for air conditioners. Thus, steel accounts for large proportions of the materials used in home appliances, although its use has somewhat decreased since recycling began in earnest.²⁾ Steel, which is an abundantly available low-cost material has long been employed for home appliances because of its strength and formability. Since the

1970s, the use of surface-treated steel sheet having better corrosion resistance (longer life) and aesthetic appeal has been increasing. Surface-treated steel sheet has been subjected to plating, conversion coating or painting to impart good corrosion resistance to the steel sheet. For indoor home appliances, electro-galvanized steel sheet with a coating weight of 20 g/m² is normally used. The purpose of this is to restrain red rust on steel by taking advantage of the preferential corrosion (sacrificial protection) of zinc under general conditions.

Fig. 2 shows the change in domestic output of surface-treated steel sheet over the past 30 years.³⁾ Thanks to the progress of surface treatment technology and a surging economy, production of surface-treated steel sheet increased markedly in the 1980s. After peaking in 1991, production remained almost stable, although it temporarily decreased in the wake of the collapse of the bubble economy. In the 2000s, production began to recover. In 2007, right before the Lehman shock, it rebounded to about 18 million tons per year. This corresponds to about 20% of the output of ordinary cold-rolled steel. In terms of the quantity of surface-treated steel sheet ordered by use, home appliances and OA equipment account for some 14% (in 2007), following automobiles and buildings.³⁾

In order to supply materials which directly or indirectly support home appliances and OA equipment indispensable for our comfortable lives, the Nippon Steel Corporation Group has tackled the development of technologies to meet the diverse needs of the market. The contribution to energy savings through reduced iron loss of non-oriented electrical steel sheet for motors and the development of stainless steels with good corrosion resistance and aesthetic appeal

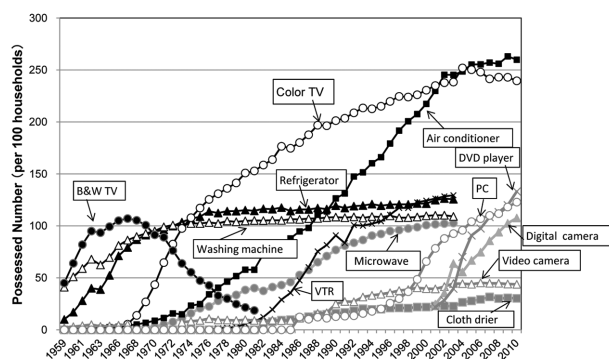


Fig. 1 Change in possession of main durable consumer goods

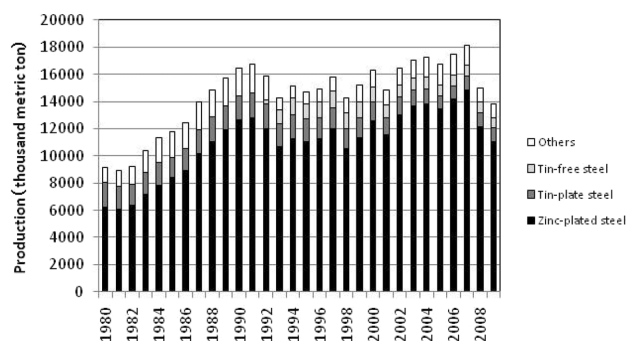


Fig. 2 Change in coated steel production

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may be cited as cases in point. For surface-treated steel sheets for home appliances as well, many new technologies have been developed over the past 30 years. In the field of home appliances in which there are many different needs, major importance is attached not only to corrosion resistance but also to formability and design. Therefore, the development of post-treatment technology applicable to plated steel sheet has contributed much to the progress of technologies in this particular field. The starting point was an organic composite-coated steel sheet developed in the early 1980s. This is a steel sheet with a silica-containing organic film formed on the chromate-treated surface to impart an anti-fingerprint property, corrosion resistance and aesthetic appeal to the steel sheet.

In this technical review, we describe examples of technological developments at Nippon Steel Corporation, with the focus on post-treatment technology, from the standpoint of: (1) developing products to enhance the efficiency of user processes, (2) developing environment-friendly products, and (3) developing products which impart new functions to existing products. We also describe recent activities by the company.

2. Nippon Steel Corporation's Activities in the Field of Home Appliances/OA Equipment

2.1 Development of products to enhance user process efficiency

During the period from the late 1980s to the early 1990s, Nippon Steel Corporation was active in developing new steel products to enhance the process efficiency of home appliance makers and thereby help to cut manufacturing costs and improve working conditions. Here are two cases in point. One is a steel sheet with lubricating film, whose organic film has sufficient lubrication to permit dispensing with any lubricant during press forming and omitting the degreasing process. The other is a pre-painted steel sheet that permits the home appliance maker to omit the painting process.

2.1.1 Steel sheet with lubricating film that permits omitting the degreasing process

In many cases, galvanized steel sheet used for home appliances requires press forming. In such cases, in order to reduce friction between the steel sheet and dies and thereby prevent defects in forming and damage to the dies, it is common practice to use a brand of press oil with good lubricating properties in the press forming process and then degrease the press-formed steel sheet. Steel sheet with lubricating film has a lubricant (wax)-containing, self-lubricating organic film formed on its chromate-treated surface. It was developed to enable continuous press forming without using any press oil. The application of steel sheet with lubricating film has permitted home appliance makers to omit their painting and degreasing processes. Thus, it has helped improve their working environment through the reduction of oil fumes and suchlike. In addition, it has contributed to reducing the environmental load through omission of the degreasing process, which had used specific CFCs and trichloroethane, etc. that were banned in 1996 as substances harmful to the ozone layer. **Fig. 3** schematically presents the steel sheet with lubricating film. It consists of a plated steel sheet with a chromate-treated surface on which an

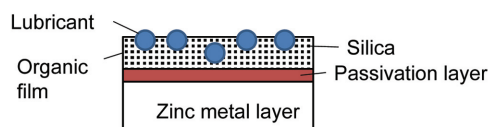


Fig. 3 Film structure of lubricated steel sheet

organic film containing lubricant and silica is formed.⁴⁾

The resin used in the above steel sheet was designed by Nippon Steel Corporation. Concerning the lubricant added to reduce the frictional force at the interface between the dies and the lubricant film, the company carefully controls the type, amount of addition, grain size and distribution of the lubricant so that the steel sheet can be moved smoothly between the dies and the punch and formed into a complex shape without breaking even with a strong force applied.⁵⁾ The lubricity of steel sheet obtained by application of the ordinary press lubricant, expressed in terms of the coefficient of kinetic friction, is in the range 0.10 to 0.15. It is around 0.06 even when a high-grade lubricant is used. The coefficient of kinetic friction of the steel sheet with lubricating film is 0.06 without using any press lubricant. There are two types of steel sheet with lubricating film that differ in performance. One is the thin-film type (1 μm in thickness) that has superior weldability and electrical conductivity, and the other is the thick-film type (3 μm in thickness) that has superior deep-drawability and corrosion resistance.⁶⁾

When steel sheet with lubricating film is used for the cartridge tank of an oil-powered fan heater, for example, since the film itself plays the same role as paint with good corrosion resistance, the prescribed corrosion resistance can be secured even if the painting process after press forming is omitted. As a base resin, a polyurethane-based resin has been adopted in view of the relationship between tensile strength and elongation. The lubricant is mainly a polyethylene based. From the standpoint of maintaining a high elastic modulus even under temperature rises in continuous press forming, studies have been made on introducing a self-bridging type using the silanol group, etc.⁷⁾

The underlying concept is that the resin used for film is designed and developed based on an understanding of the properties of various base metals, plating types and resins, and that the lubricant and other functional materials are designed so as to develop various types of films with not only high lubricating performance, but also good corrosion resistance, formability, and electrical conductivity, etc. This concept has also been applied to the development of various films for surface-treated steel sheets.

2.1.2 Pre-painted steel sheets

Pre-painted steel sheet—a steel sheet previously painted at the steelworks—has enabled the customer to omit the degreasing and painting processes and restrain the occurrence of volatile organic compounds (VOCs). Nippon Steel Corporation marketed its first pre-painted steel sheet (trade name: VIEWKOTE™) in 1994. The typical structure of pre-painted steel sheet is shown in **Fig. 4**. It consists of a pre-treatment coat, which manifests adhesion with the plating, a

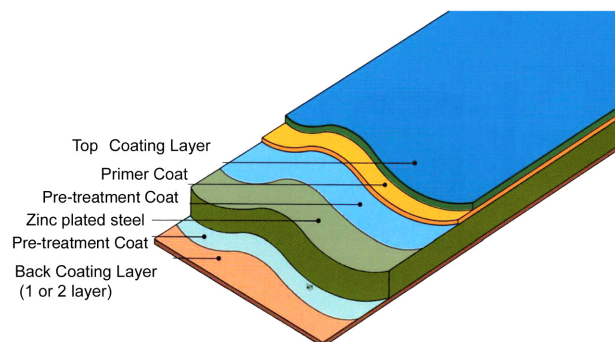


Fig. 4 Structure of pre-painted steel sheet

rustproof primer coat, and a topcoat, which manifests aesthetic appeal and the prescribed functions.

The technical problem involved in commercializing a pre-painted steel sheet is that a certain measure of formability is required of the coating. The reason for this is that unlike conventional post-painted steel sheet that is painted after it has been worked on, the pre-painted steel sheet is painted before it is worked on. Therefore, the company studied the relationships between formability and coating properties and clarified that the higher the coating elongation percentage, the better the bending formability, and that the smaller the elastic strain energy, obtained from the coating stress-strain curve, the more effective the drawability becomes. The relationships between those properties and the glass transition point (T_g) of the coating have been classified into patterns and utilized for optimum design of the coatings.⁸⁾ On the other hand, from the standpoint of stain resistance, it is desirable that the degree of cross-linkage should be increased to make the coating harder. However, it is difficult to secure both good formability and good stain resistance in a coating of simple structure.

Under that condition, Nippon Steel Corporation developed a coating with a gradient structure (trade name: VIEWKOTE™ IV) that is hard outside and soft inside. This is obtained by evaporating from the surface layer of coating the amine that blocks the acid catalyst in the coating during the heating and drying process so as to activate the acid catalyst and promote the self-condensation reaction of melamine-formaldehyde in the polyester resin, so that hard melamine-formaldehyde resin is enriched near the coating surface. Thus, a hard surface layer is provided to make it difficult for stain to soak into the coating, while the inside of the coating remains soft by reducing the concentration of melamine-formaldehyde resin so as to afford good formability (Fig. 5).⁹⁾

The pre-painted steel sheet was originally developed as a structural steel material. However, as the pre-painted steel sheet afforded good formability and other benefits required of home appliances, it eventually came to be used for the housings of home appliances as well. During the 1990s, the use of pre-painted steel sheet for heaters, lighting fixtures, refrigerators, washers, air conditioner outdoor units, etc. increased rapidly. In the 2000s, pre-painted steel sheet has also been used for housings and back cover of DVD players, flat-panel TVs, etc.¹⁰⁾ Pre-painted steel sheet accounts for a large proportion of the steel materials used for home appliances. For many other products that do not require welding, pre-painted steel sheet has also been increasingly used.

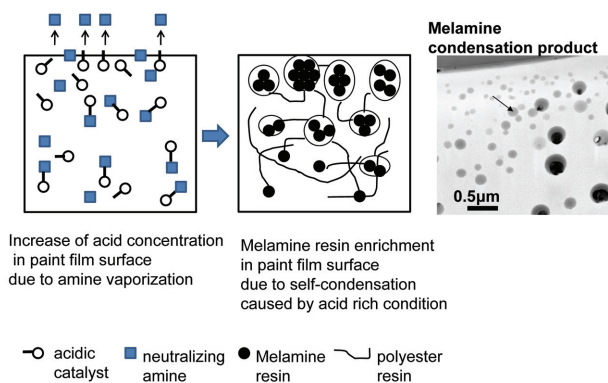


Fig. 5 Mechanism of melamine resin enrichment paint film surface and cross sectional image by TEM

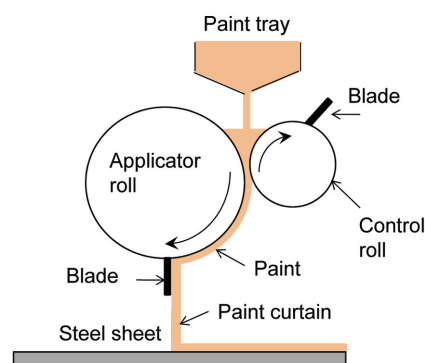


Fig. 6 Schematic view of curtain coater developed

The commercialization of pre-painted steel sheet has promoted the development of new process technologies as well. Ordinarily, a roll coater is used when manufacturing pre-painted steel sheet in roll to roll process. The main reasons for this are: the roll coater is relatively simple in construction; it allows the coating thickness to be easily and accurately controlled by adjusting the roll peripheral speed and roll gap; and the viscosity range of applicable paint is wide. On the other hand, when a roll coater is applied to a rigid steel sheet, it is necessary to pay special attention to any variation in coating thickness across the width and the amount of roll wear (frequency of roll change).

A curtain coater is used in the process of manufacturing cut-length pre-painted steel sheets. The curtain coater is a non-contact type that applies to the steel sheet a paint curtain which drops from a slit in the bottom of the paint tray. With the coater, it is easy to obtain a smooth, beautiful appearance. On the other hand, it can hardly be applied to a continuous coating process since the coating thickness needs to be controlled by adjusting the slit width and steel sheet speed.

Nippon Steel Corporation has developed and put to practical use a roller curtain flow coater that is a hybrid of the above two types of coaters. The paint that is supplied from the above two rolls (applicator roll and doctor roll) is weighed by those rolls rotating in the opposite direction, scraped off by a blade installed at the bottom of the applicator roll, and forms a curtain as it flows down (Fig. 6). The coating thickness can be controlled by adjusting the roll peripheral speed and the roll gap. With this coater, it is possible to obtain a smooth and beautiful coat. This technique permits applying even coatings containing a metallic flakes or resinous beads that tend to cause uneven roll transfer, thereby making it easier to impart various designs and functions to the coat. In addition, there is the possibility that it can be high-speed coating since the hybrid coater is a non-contact type and it can be applied to multilayer coating using the wet-on-wet technique that coats one wet layer on another without drying.¹¹⁾

2.2 Development of products that help reduce environmental impact

From the standpoint of protecting the environment, the movement to avoid using substances that have an adverse effect on the environment is gaining momentum. In Europe, the EU Directive RoHS (Restriction of Hazardous Substances in electrical and electronic equipment) was promulgated in February 2003 and came into effect in July 2006. Specifically, the RoHS restricts the use of six types of chemical substances specified (maximum concentration

1,000 ppm for lead, mercury, hexavalent chromium, polybrominated biphenyl, and polybrominated diphenylether, respectively, and 100 ppm for cadmium).¹²⁾ Although the addition of chemical substances subject to the above restriction was shelved, a revised RoHS directive embracing the addition of products subject to the restriction, the obligation to attach a CE label to every conforming product, etc. is due to come into effect within 2011.

In Japan also, in response to the above movement, more and more companies are pressing ahead with green procurement. In 2000, the Law Concerning the Promotion of Procurement of Eco-friendly Goods and Services by the State and Other Entities (Green Purchasing Law) was enacted.¹³⁾ Concerning the seven items (personal computers, unit-type air conditioners, TVs, refrigerators, washing machines, microwave ovens and clothes driers) containing chemical substances specified in JIS C 0950 (J-MOSS), the Law for Promotion of Effective Utilization of Resources, revised by a government ordinance in 2006, provides that if any of the specified values (same as those of the RoHS directive) is exceeded, it shall be indicated by the prescribed mark (orange) attached to the product in question.¹⁴⁾

Under those conditions, Nippon Steel Corporation was quick to cope with elimination of hexavalent chromium (and finally chromium) from the chromate coating used to impart better corrosion resistance to galvanized steel sheet and elimination of lead from solder-plated steel sheet in the 1990s. As a result, early on the company could commercialize eco-friendly products.

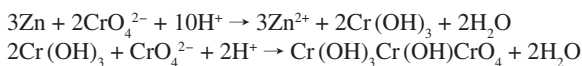
2.2.1 Chromate-free technology

(1) Function of chromate film

The purpose of galvanizing is to restrain the base steel from rusting using the sacrificial protection of zinc. However, zinc produces white rust when oxidized for a long time. This is a chemical treatment that is applied to prevent the white rust. Chromate treatment using chromic acid is a common method of chemical treatment for that purpose. It has been widely applied to various types of surface-treated steel sheets, including galvanized steel sheet, as an effective and inexpensive method for primary rust prevention (i.e., preventing the galvanized steel sheet surface from rusting in the maker's processes from working on the steel sheet to assembly of the steel sheet into the final product) and for pre-treatment before painting.

The thin film of chromate formed by chromate treatment has: (1) a shielding function that prevents oxygen and water—corrosion factors—from reaching to the zinc plating surface, (2) a self-repairing function—the salient characteristic of the film—when the metallic zinc is exposed as a result of damage to the film, and (3) a function to improve the paint adhesion.

The above functions can be expressed by the following equations.



As zinc is dissolved, the hexavalent chromium is reduced to trivalent chromium. Then, as H^+ is consumed, the pH value increases. As a result, the trivalent chromium precipitates in the form of chromium hydroxide, $\text{Cr}(\text{OH})_3 \cdot n\text{H}_2\text{O}$, and covers the coating surface. It is estimated that the chromium hydroxide partially reacts with the residual hexavalent chromium and precipitates. Since trivalent chromium is hardly reduced or dissolved in water, the film composed mainly of trivalent chromium has a shielding effect. When the metallic zinc is exposed as a result of damage to the film, the water-soluble hexavalent chromium dissolves from the film and reacts with the zinc to become trivalent chromium, which repairs the damaged film and restrains the occurrence of white rust. Namely, thanks to the

presence of a very small amount of hexavalent chromium in the chromate film, the damaged film is quickly repaired. This is the self-repairing function that affords an excellent rust-prevention effect.

(2) Development of chromate-free film

However, the hexavalent chromium contained in the bath used for chromate treatment is an environmentally hazardous substance. Therefore, it was indispensable to use a bath free of chromate. Nippon Steel Corporation successfully developed chromate-free films ahead of other companies and commercialized (trade names: Electrogalvanized Chromate-free Steel Sheet ZINKOTE™ 21 and Hot-Dip Galvanized Chromate-free Steel Sheet SILVERZINC™ 21).

The point in the development of the above products was to distribute the shielding, self-repairing, and coating adhesion functions of chromate film not to a single substance but to more than one substance other than hexavalent chromium. Basically, a base resin with good shielding and coating adhesion functions is added with a corrosion inhibitor affording a self-repairing function. There are several types of corrosion inhibitors: an adsorption type that adsorbs monoatomic molecules to the surface of a metal; an oxide type that forms a passivation film composed mainly of an oxide on the surface of a metal; a sedimentation type that sediments between the corrosive atmosphere and metal as a reaction product which intercepts corrosion factors; etc. Those corrosion inhibitors are used singly or in combination to secure the required self-repairing function (see Fig. 7).

ZINKOTE™ 21, that was first marketed in 1998, consists of an organic film. It is available in two types: QF that is a thick film with superior corrosion resistance and anti-fingerprint properties, and QS that is a thin film with superior electrical conductivity. The representative properties of those films are shown in Fig. 8.¹⁵⁾ In terms of the corrosion resistance of flat and formed surfaces measured by a salt spray test, the two films outperform chromate film. They are also superior to chromate film in dynamic friction coefficient and scratch resistance.

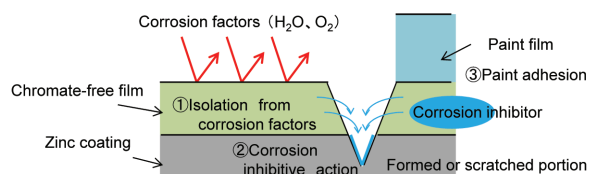


Fig. 7 Corrosion protection mechanism of chromate-free film

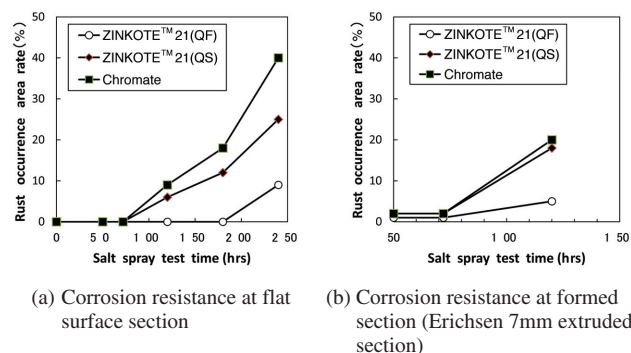


Fig. 8 Properties of chromate-free film¹⁵⁾

Nippon Steel Corporation made further improvements on its chromate-free films. In 2007, the company commercialized several new films, including organic films, QF1 and QS1, which have improved the resistance to scratching and chemical reagents, and an inorganic film, QM, which is superior to QS1 in electrical conductivity and coatability.

The company pressed ahead with the application of chromate-free film to pre-painted steel sheet as well. It succeeded in making both pre-treatment coating and primer coating free of chromate and commercializing chromate-free, pre-painted steel sheets not only for home appliances for indoor use,¹⁶⁾ but also for home appliances exposed to severe corrosive atmospheres.¹⁷⁾ From the results of a three-year exposure test carried out in Okinawa, it has been confirmed that the chromate-free, pre-painted steel sheet is superior to the post-painted steel sheet in edge corrosion resistance and almost comparable to the pre-painted steel sheet with chromate film in every respect.¹⁸⁾

2.2.2 Lead-free technology

(1) Lead-free Zn-Sn-Ni alloy-plated steel sheet

Lead-free steel sheet is required mainly for circuit boards, chasses, and other electronic parts in home appliances that are to be soldered. Nippon Steel Corporation had been supplying a terne-coated steel sheet—a Pb-Sn alloy-plated steel sheet with good wettability with solder (Pb-Sn alloy). However, in order to meet the demand for lead-free steel sheet, the company started development of new types of plating.

In the development, the emphasis was placed on Sn, which is the basic component of solder. In 1991, the company commercialized a lead-free, Zn-Sn-Ni alloy-plated steel sheet (trade name: ECO-TRIO™) having good wettability with conventional solder and lead-free solder. ECO-TRIO™ is obtained by first electroplating Ni, Sn and Zn to the base metal in that order and then heating and fusing them into an alloy. As a result of heating and fusing, two alloy layers are formed—a layer composed of Ni-Zn alloy and Sn-Ni alloy on the base metal and a layer of Sn-Zn alloy on the first layer (Fig. 9). The Sn-Zn eutectic alloy of the upper layer has a low melting point and provides good wettability with solder, and the sacrificial protective action of Zn and the uniform Sn coating owing to lower Ni plating layer secure good corrosion resistance. Needle crystal whiskers which tend to be formed easily in Sn plating and which can cause short circuits are reduced by: (1) relieving of internal stress by heat treatment and the resultant decrease in driving force for surface migration, and (2) weakening of surface migration by Zn addition.¹⁹⁾

²⁰⁾ At present, chromate-free chemical treatment is also applied to reduce the environmental impact.

(2) Other lead-free technology

The free-cutting lead steel with good machinability used for shafts, etc. of OA equipment is not subject to the RoHS directive. However, in order to help reduce use of this environmentally hazardous substance, Nippon Steel Corporation strove to develop lead-free, free-cutting steel, as surface-treated steel sheet, on the basis of a clarified

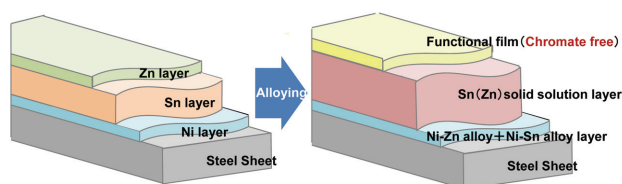


Fig. 9 Film structure of Pb-free Zn-Sn-Ni alloy plating

cutting mechanism. As described in the technical review relating to automotive steel sheet (see Chapter 1, 1-1), the company successfully developed lead-free free-cutting steel with good machinability secured by controlling the form of MnS precipitates.²¹⁾

2.3 Development of products with new functions

Since the late 1990s, aside from further enhancing the basic properties of surface-treated steel sheet (corrosion resistance and formability), Nippon Steel Corporation has developed new products equipped with various new functions that offer direct comfort to our five senses. Those functions include, for example, aesthetic appeal, stain resistance and reflectivity (vision), quietness and vibration control (hearing), heat absorption/radiation and heat isolation (feeling), and environmental friendliness, including sanitation. The company's development roadmap for imparting new functions to surface-treated steel sheets is shown in Fig. 10.

2.3.1 Improvements in corrosion resistance

Good corrosion resistance is required of home appliances for outdoor use, such as an air conditioner's outdoor unit. Therefore, hot-dip galvanized steel sheet with a thick layer of zinc or Zn-Al alloy-plated steel sheet as used for buildings is commonly applied to those home appliances. Nippon Steel Corporation found that its Zn-5%Al alloy-plated, corrosion-resistant steel sheet that had been put to practical use as a structural material improved in corrosion resistance when the Al content was increased and Mg and Si were added.²²⁾ Based on that finding, the company developed a new alloy-plated steel sheet, Zn-11%Al-3%Mg-0.2%Si (trade name: SuperDyma™), which was marketed from 2000.

The salient characteristics of the Zn-11%Al-3%Mg-0.2%Si alloy plating are that the corrosion resistance of the flat surface is about four times that of hot-dip galvanized steel sheet, as measured in an exposure test,²³⁾ and that the cut edge is prevented from corroding as it is covered with a dense protective film composed of $\text{Zn}(\text{OH})_2$, $\text{ZnCl}_2 \cdot 4\text{Zn}(\text{OH})_2$, $\text{Mg}(\text{OH})_2$, etc. eluted from the plating.²⁴⁾ Because of its outstanding durability, the alloy-plated steel sheet has been increasingly employed for steel flooring and, more recently, solar panel framework. It is also being applied to air conditioner outdoor units. According to the results of a 9.5-year exposure test, a chromate-free, pre-painted steel sheet made from the Zn-11%Al-3%Mg-0.2%Si alloy-plated steel sheet is far superior in corrosion resistance to a chromate-free, pre-painted steel sheet made from a hot-dip galvanized steel sheet.²⁵⁾

2.3.2 Control of appearance

Amid increasingly sophisticated demands for the attractive

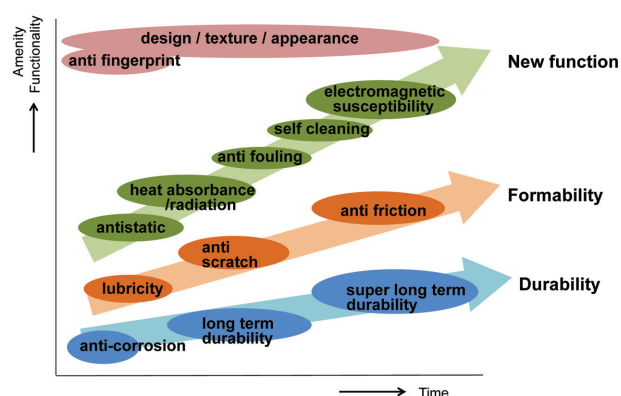


Fig. 10 Roadmap of function of coated steel sheet

appearances of home appliances, Nippon Steel Corporation's original technology—"orange peel" steel sheet—has expanded the market for pre-painted steel sheets. Conventional pre-painted steel sheet was characterized by a glossy surface free of irregularities. By intentionally forming mm-order irregularities resembling orange peel on the steel sheet, it is possible to render scratches on the film on the steel sheet less conspicuous and facilitate the customer's improved efficiency in handling the steel sheet. The technology involved in the orange peel steel sheet is this. First, a thermal melting resin which differs in surface tension from the base resin is added so that irregularities caused by the difference in surface tension between them are formed immediately after the paint coating is applied. Then, in the succeeding baking process, the irregularities formed are smoothed out and rendered into mm-order irregularities.²⁶⁾ Unlike the formation of surface irregularities by addition of a pigment or aggregate, the above technology represents a new approach to film design that changes only the surface structure without affecting the formability, stain resistance and other performances of the original film.

2.3.3 Imparting new functions

Pre-painted steel sheet is fabricated into a wide variety of final products by various processes, such as cutting, punching and pressing. Ordinarily, the film of pre-painted steel sheet is an insulating material. Therefore, when the film makes contact with some different material (e.g., belt conveyor) in the assembly process, it may become charged with static electricity as a result of friction or detachment. If this occurs, dust tends to deposit on the surface of the film. The most common method of preventing static electricity is imparting electrical conductivity to the film by adding an antistatic agent or metal to it. In this respect, Nippon Steel Corporation clarified that in order to restrain the deposition of dust onto the film caused by static electricity generated as a result of friction, it is necessary to restrain the generation itself of static electricity by friction. Eventually, the company developed a suitable antistatic additive to the resin and commercialized an antistatic steel sheet containing that additive.²⁷⁾

For home appliances for outdoor use, Nippon Steel Corporation has also commercialized a self-cleaning type of steel sheet that displays good stain resistance while the product is used. This steel sheet has a silicate-containing hydrophilic film on the surface.²⁸⁾ In rainy weather, raindrops sink under the dust accumulated on the film, and wash it away. Since the film also restrains the formation of a pattern of water scale, which is often seen on conventional pre-painted steel sheets (Fig. 11), it should be able to help reduce the maintenance burden. In addition, since the outermost layer of the film is a transparent one, it is possible to form the film on any tinted layer. The self-cleaning type of steel sheet is used for air conditioner outdoor

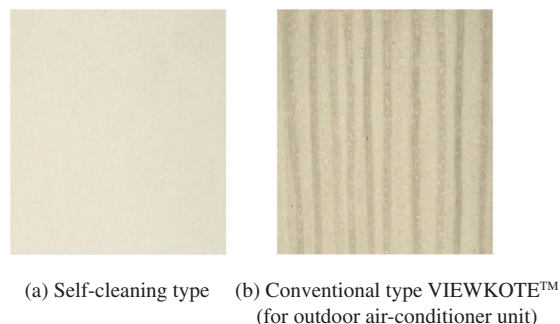


Fig. 11 Appearance after 1.5 year outdoor exposure test

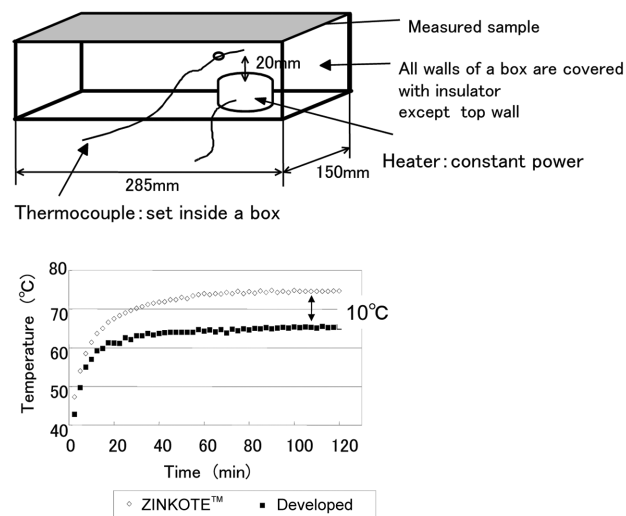


Fig. 12 Property of heat absorption type steel sheet²⁸⁾

units, heat pump water heaters, and cogeneration systems for home use, etc.

In recent years, with the enhanced performance of home appliances, the heat emitted from them has increased. On the other hand, their components have been increasingly integrated and miniaturized. As a result, the thermal load per unit volume has increased. Under those conditions, in order to protect the heat-sensitive electronic parts, it is necessary to efficiently radiate the heat generated inside the electric apparatus. In view of that need, Nippon Steel Corporation has developed a "high heat absorption steel sheet" which has a highly emissivity film on the heat source side (back of the steel sheet) so that the heat generated inside the housing can be efficiently radiated to the outside. The salient characteristic of this steel sheet is that each side of the steel sheet is provided with a film having high emissivity based on the molecular design of the constituent resins and added substances/pigment, and that electrical conductivity (grounding) required of the steel sheet is secured. Compared with conventional galvanized steel sheet, the newly developed steel sheet makes it possible to lower the temperature inside the housing by as much as about 10°C (Fig. 12). Therefore, it has found applications for housing covers of DVD/HDD players, vehicular devices, etc. It is expected that the new steel sheet will help cut the cost of home appliances since it permits dispensing with a radiator fan, reducing the number of openings for heat dissipation, and so on.²⁹⁾

2.4 Recent activities

2.4.1 Thin-film coated steel sheet

The "ZINKOTE™ Black", a black electro-galvanized steel sheet that Nippon Steel Corporation commercialized for the back cover of flat-panel TVs in 2009, has a film configuration different from that of the conventional pre-painted steel sheet. A newly developed, water-based coating that can be dried under low temperature conditions has made it possible to obtain a film 70% to 80% thinner than that of the conventional pre-painted steel sheet (Fig. 13). The reduced film thickness and the implementation of in-line electro-galvanizing using a water-based coating have helped cut the cost and reduce VOC emissions.³⁰⁾ Characteristically, the film conceals color well even though it is only about 5 μ m in thickness. This was made possible

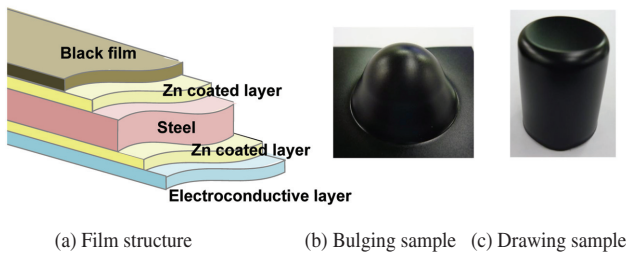


Fig. 13 Film structure and forming samples of ZINKOTE™ Black

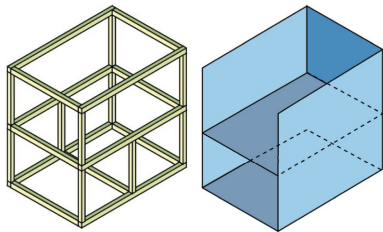


Fig. 14 Image of frame and box subject to evaluation

by advanced pigment dispersion technology. In order to make the thin film manifest good corrosion resistance and formability, the base resin was optimally designed.

2.4.2 “Katachi” solution

As described in the technical review under “Steels, Steel Products and Steel Structures Sustaining Growth of Society (Infrastructure Field)” (see Chapter 1, 1-4), in the field of residential housing, Nippon Steel Corporation has conducted R&D into light-gauge steel structures, including steel framed houses, since 1994. If the structural problems ascribable to the buckling of steel members can be resolved, it becomes possible to benefit from flexibility of shape, such as roll forming, which are unique to light-gauge steel structures. Therefore, the company has pressed ahead with R&D into technology in order to evaluate torsional property and buckling design of light-gauge steel structures, with the emphasis on developing light-gauge steel members that have a unique cross section.³¹⁾

At present, the company is striving to apply its steel sheet structure design technology to small structures, rather than conventional architectural structures. Specifically, the company is proposing steel structures that help enhance the stiffness and strength of home appliances (e.g. washing machines and air conditioner outdoor units) or OA equipment (e.g. copiers and printers). Since the solutions for effective utilization of steel sheet are offered with an eye on shape, the company calls the activity “Katachi” solution. “Katachi” is a Japanese broader term meaning member shapes and structural configurations. For the purpose of proposing structural optimization, the company divides a steel structure into a framework consisting of steel bars (left-hand diagram in Fig. 14) and a box consisting of steel sheets (right-hand diagram in Fig. 14) so as to simplify the design process into the cross-section design of bars and sheets and the structural design of a framework and a box.

2.4.3 Joining solution

In home appliance/OA equipment manufacturing processes, various joining methods are applied, such as screwing, caulking and welding. When a galvanized steel sheet is welded, there is the fear

that the corrosion resistance and aesthetic appeal of the steel sheet will decline at the welds. Nippon Steel Corporation has been tackling development of the following welding and joining technology that takes into consideration the securing of corrosion resistance and aesthetic appeal of welds.

(1) Highly corrosion-resistant welding material requiring no touch-up: When zinc-plated steel sheets are joined together by arc welding, there is the potential for the input heat during welding to vaporize the plating component of low melting point, causing the corrosion resistance of the steel sheet to decline. In this case, it is necessary to touch up the weld after welding. For a plated steel sheet with superior corrosion resistance, it is especially important to secure corrosion resistance of the weld. Therefore, Nippon Steel Corporation has developed for the highly corrosion-resistant Zn-11%Al-3%Mg-0.2%Si plated steel sheet a new welding material that does not need a touch-up after welding.³²⁾ The new welding material applies a welding material for stainless steel to secure corrosion resistance of the weld (Fig. 15). In addition, in order to avoid the brittle cracking of zinc—a problem with the welding material for stainless steel, the composition of the new welding material has been adjusted to secure good mechanical properties. Concerning the heat-affected zone at the back of the weld where corrosion resistance tends to deteriorate easily, it has been found that the corrosion resistance of Zn-11%Al-3%Mg-0.2%Si steel sheet is much better than that of ordinary galvanized steel sheet since the residual Al concentration of the weld is considerably high.³³⁾ The new welding material has been increasingly applied to such structural components as carports and steel racks. It is expected that in the future it will also be applied to home appliances exposed to severe corrosive atmospheres.

(2) Welding with low input heat: When welding a thin plated steel sheet, technology for minimizing the thermal damage caused by the welding is called for. For precision instruments, there is also a strong demand for clean welding that restrains the occurrence of spatters. In order to meet those needs, Nippon Steel Corporation has built solution technology utilizing the latest welding equipment. For example, laser welding is known as a high-precision welding technique that allows for a low heat input. In recent years, remote-controlled laser welding that permits enhancing productivity has come to be applied mainly by automakers. It is expected that this technology will be applied to steel frameworks and suchlike which have many points to weld. Concerning arc welding, it has become possible to implement low-spatter welding of thin steel sheets by utilizing a CMT

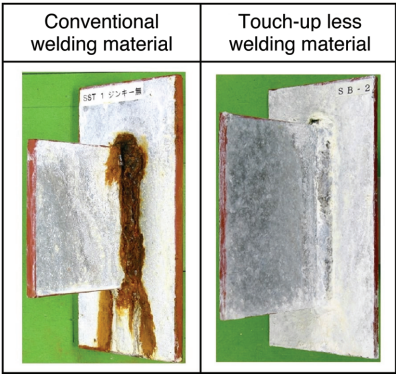


Fig. 15 Accelerated corrosion test result of welded parts in Zn-11%Al-3%Mg-0.2%Si coated steel sheets (5% salt spray test, 1,000 h)

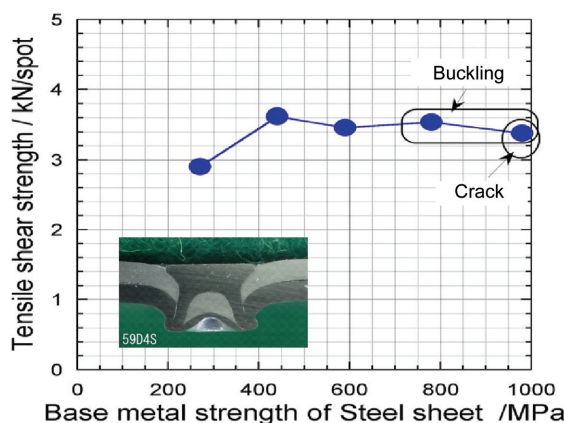


Fig. 16 Strength of riveting joints for steel sheet and aluminum alloy

(Cold Metal Transfer) power supply. With respect to mechanical joining which requires no heat input (e.g., riveting or caulking), Nippon Steel Corporation has also studied the influence of joining conditions on joint strength and has been accumulating relevant data by conducting fatigue and corrosion resistance tests, etc.³⁴⁾ Fig. 16 shows the strength of rivet joints between a steel sheet and an aluminum alloy sheet. It can be seen that the rivet joints exhibit stable strength, whereas it has long been known that welded joints decline in strength as a result of the formation of a brittle intermetallic compound. Nippon Steel Corporation aims to expand the application of its steel sheets by offering the above solution technology.

3. Outlook for the Future

Globally, backed by the economic growth of the NIES, the market for home appliances and OA equipment is expected to continue expanding. On the other hand, the domestic market has entered a period of maturity. Therefore, the shift of domestic production bases of our customers to NIES, the local procurement of materials made reasonable as a result of improved skills in the NIES and competition between steels and other materials like plastics will become more conspicuous than ever before.

Under those conditions, as surface-treated steel sheets for home appliances, it is necessary for Nippon Steel Corporation to provide new steel sheets in a timely fashion that not only have good recyclability and high strength, but also the aesthetic appeal and functions that are really requested by its customers. Concerning the steel sheet functions, since the problems of thermal load and electromagnetic wave leak will remain unsolved in view of the continual miniaturization of products and the continual integration of their parts, it is to be desired that the performances of endothermic steel sheets and electromagnetic shielding/absorbing steel sheets should be enhanced. In addition, in view of the ever-increasing numbers of long-life products, such as LEDs, and power generation- and storage-related products for home use that call for long-term durability, it is considered that the functions that significantly reduce the burden of maintenance, such as stain resistance, resistance to dust deposition (antistatic function) and long-term corrosion resistance, will continue to be important properties of steel sheets in the future. From the standpoint of securing those functions, it will become necessary not only to optimize the conversion coatings and films but also to implement optimum design of surface-treated steel

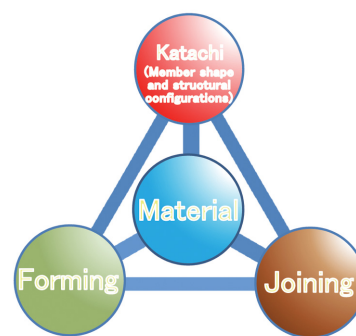


Fig. 17 Synergy effect including “Katachi” solution

sheets including plating films.

It is indispensable to establish technology to cut the costs of steel sheets while enhancing their added values by imparting the above functions to them. To that end, utilizing and developing the thin-film coated steel sheet described above is one approach that can be taken. Reducing the thickness of coating film necessarily sacrifices some properties. Therefore, it will become important not only to implement more sophisticated film design than ever before, but also to distribute the functions between those films and plating. Innovations in process technologies will also be required. There is no doubt that it will become indispensable to build technology to form films speedily and easily.

Furthermore, by utilizing the synergism (Fig. 17) of raw materials technology and the company’s own solution technologies—joining technology (welding, caulking, bonding, etc.) with forming and processing technology (roll forming, hydroforming, etc.)—and “Katachi” solution, Nippon Steel Corporation would like to positively propose solutions to reduce the total cost through the use of steel materials and thereby win its customers’ trust and expand the application scope of its steel products.

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