Essay from the Marketing Department

The Unremitting Evolution of Steel Sheets

– Its mission and pride as the spark of industrial innovation –

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Abstract

Steel has a long history. It is a history of researchers and engineers overcoming challenges by dedicating their effort and wisdom to meet the needs of society. The challenge still continues today. The evolution of steel is unremitting. In this essay, while looking back on the history, I will provide some brief and systematically organized introductions using the articles of our various cutting-edge technology on "Steel Sheets for a Comfortable Life" published in this Nippon Steel Technical Report. We take on the challenge of describing the "now" and "future" of innovation in such a way that is as clear and easy to understand as possible from a marketing and sales perspective. Our technology has always led the innovation. It is our mission to exceed everyone's expectations. With the pride of Nippon Steel.

1 Introduction

1.1 A short history of iron and steel

A *tatara* refers to an iron-smelting site where iron is extracted from iron sand. In *Princess Mononoke*, a film written and directed by Hayao Miyazaki, a *tatara* is depicted as an important place that is key in the story. Ashitaka, the main character, meets Eboshi Gozen at the *tatara* in the course of a journey to find a way to lift the curse that was put on him by a demon. He gets to know what the curse is and eventually gets involved in a struggle between humans and the gods of a forest.[1)]

There had been such iron-smelting sites around Japan since ancient times, and they had been satisfying the demand for iron in Japan for a long time. But during the Meiji period, modern ironmaking processes that came from the West started to become common, and the old method gradually diminished. Currently, there is only one such *tatara* iron-smelting site, called "Sugaya Tatara" and located in Yoshida-cho, Unnan City, Shimane Prefecture, which is the scene of many myths.[1)]

Times always change. In this, there is a history of civilization that has been continuing to evolve so as to satisfy various people's needs.

For example, the tools that humans have used historically have advanced from stoneware to bronzeware and then to ironware, which brought considerable progress.

Ironmaking technology is regarded as one of the most-important inventions in human history. When and where it was invented is not precisely known. But recent studies indicate that it was developed in Anatolia near Ankara, the capital of Turkey, in ancient times—approximately 4 000 years ago (before 2000 B.C.)— and the Hittites, who had migrated to this area, started using the technology regularly.

It is considered that the Hittite Empire advanced ironmaking technology subsequently and that the Tatar people, descendants of Hittites, introduced the technology to India and China. Ironware came to Japan during the Yayoi period, and it is said that in around 400 A.D., people started ironmaking at the aforementioned *tatara* sites (with some people saying that the term *tatara* came from the aforementioned "Tatar peoples").

Why has iron spread across the world and why did it become an item essential for daily living?

In the beginning, people frequently used stoneware, made by chipping and grinding stones. However, stoneware comes with various problems in performance, i.e., of course, stones are difficult to process into special shapes, they are hard but easily break, and once a stone tool breaks, it cannot be repaired. After that, metal casting technology was developed, so people started using metal tools fre-

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quently because metals that soften when heated can be processed into any shape and can be reused by melting them. Over history, harder, tough, easy-to-process, and low-priced iron appeared as an abundant resource, and this started the period of ironware following the period of bronzeware. It is not too much to say that your living has advanced together with iron, resulting in affluence.

1.2 Does steel/iron have something in common with wheat?

I sometimes feel that steel/iron has something in common with wheat (i.e., in that factories for producing iron and flour are both called "mills"). To allow you to understand iron more and to make it more familiar, I will use some space here to compare iron with wheat.

Milling companies produce flour from wheat and wholesale it to manufacturers of bread (41%), noodles (33%), confectionery (12%), and the food services industry (11%), or they sell to households via retailers as flour for household use (3%) (based on actual sales in FY2014).[2)]

There are many wheat types, so it is important to select an appropriate wheat type that matches what you will cook. Usually, strong flour is used for bread, pizza, and Chinese noodles, medium-strength flour is used for *udon*, and weak flour is used for confectionery, cakes, and *tempura*. Some people might pay substantial attention to flour types, saying that durum wheat semolina is the best for fresh pasta.

There are also many types of steel (iron) products. Focusing on shape, many types look like noodles. Examples are "hollow steel pipes" like macaroni and penne, narrow-diameter long "steel bars" and "wire rods" like spaghetti, rather "thick and flat plates" like lasagna, and "thick solid construction materials" like *udon* and *chikuwabu* (tube-shaped cakes of flour paste from the Kanto region of Japan; I know this is a little far-fetched).

Among various food products involving wheat, I sometimes especially feel that steel sheets, on which this Technical Report focuses, is like pizza. Then, the question arises: "Are flat-product steelmakers pizza chefs?" Imagine a pizza maker's work and then look at steelmakers. They surprisingly have a lot in common. I will give an example to explain this clearly.

To make pizza, you first mix and knead wheat, salt, sugar, warm water, olive oil, dry east, and other ingredients, and then you roll it out to make pizza dough. There are also various dough types: Springy hand-tossed, crunchy crispy, and fluffy pan pizza Italian. You can select whichever you like. The base sauce can be standard tomato sauce, white sauce, basil sauce, etc. What would you like to have as topping? Vegetable? Prosciutto? Cheese? Off course, you can select the size you like. I recommend and eight-slice pizza with a diameter of 25 to 28 cm for two or three of you and a 12-slice pizza with of 30 cm over for three or four of you.

When comparing a steel sheet to pizza, the thin pizza dough is the steel. There are many types of steel sheets, as is the case with pizza. Various types of products are on offer with a variety of dough types and baking conditions, from harder to sticky & springy (as material specifications). Of course, you can select the thickness (sheet thickness) and size (sheet width); and a wide variety of products are on the menu, from slightly thick dough to rather thin dough.

This Technical Report focuses on olive oil and various sauce types, such as tomato and basil sauce, which are spread onto the dough, as well as toppings that correspond to new technologies for coatings, surface treatment, and painting (**Fig. 1**). This issue introduces the finishing technologies for finishing up the "taste" and "appearance" based on various customer preferences. Please enjoy it.

1.3 History of evolution: A history of needs

Which restaurant and which dish do you select? The answer depends on the tastiness, volume, cost performance (of course), and, recently, appearance. Needs are getting more and more complicated; some want to have delicious food and some want to go to a famous restaurant, in addition to a simple desire to satisfy your appetite. In addition, some customers always select standard products, while some like unique, characteristic products. Both customers and their needs are getting more and more diversified.

In such current times, manufacturers should skillfully combine the part that we do not change and keep carefully and the other part that we always change. It is important for us to satisfy needs and expectations at present and in the future and to keep on working such that customers select our products for any length of time.

This also applies to iron. Currently, iron is seen everywhere in daily life and is very useful. This is thanks to the long history of successes in which the iron industry has been always capturing a wide variety of needs appropriately and always working to advance to satisfy such needs.

Now, in the following chapters, let me look back on the history of steel/iron and on how it has been advanced to satisfy various needs.[3)]

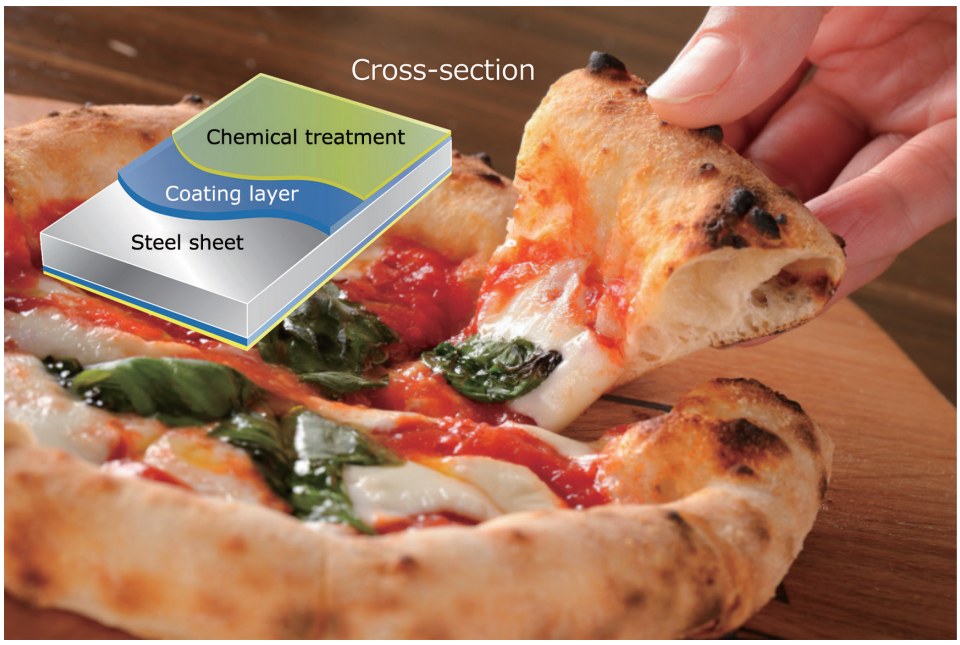

Fig. 1 Is a steel sheet like pizza?

2 In the Past

Actually, even in the ironware era that began following the bronzeware era, bronzeware was still used as ornaments and for Shinto ritual implements in Japan as used at festivals. This is because iron rusts faster than bronze, which is an alloy consisting of mainly copper and also tin, so iron was inferior in artistic quality and in expressing beauty.

2.1 Rust

Why does iron rust?

The Earth's air contains 21% oxygen. Accordingly, most metals cannot exist as pure metals, and they react with oxygen in the air to turn to oxides. Naturally, iron exists as iron ore (oxide). To obtain iron (steel), carbon (coke) is used to reduce iron ore. However, without further treatment, steel reacts with oxygen and water in the air (oxidation), transforming into a stable state. As a result of this oxidation, rust (red rust) forms. Actually, the state with red rust is the most-comfortable state for iron (**Fig. 2**).

However, if the rust is left untreated, oxidation gradually gets into the inside from the surface of the iron and breaks the iron structure up in a flaked manner. Let me explain the impact more specifically.

In a general environment (rural environment), iron rusts (corrodes) approximately 50 μm for one year. The total annual corrosion amount on both faces of a steel sheet is approximately 0.1 mm (100 μm) (50 μm [one face per year] × two faces). More specifically, for example, a 3.2-mm-thick steel sheet rusts approximately 0.32 mm (0.1 mm [two faces per year] × 3.2 years) for 3.2 years, and that is equivalent to 10% of the initial thickness. The remaining thickness (approximately 90% of the initial thickness) cannot retain the necessary yield strength, so at that point, usually it is regarded that the steel sheet has reached its life span (**Fig. 3** on the following page).

2.2 Preventing rust

Like this, although iron is easy to use, it is unfavorable if it rusts and becomes not fit for use. Accordingly, earlier peoples figured out ways to protect iron by shutting out oxygen and water, which are causes of rust, so as to prevent rust. Examples are enclosing and surface treatment, such as coating and painting (**Fig. 4** on the following page).

2.3 Coating

Coating is like "makeup" to be applied to the surface of materials to prevent rust. A typical example is the galvanization of iron. For this galvanization, the zinc "sacrifices itself" and rusts to protect the iron. Thanks to galvanization, iron is guarded against rust and its service life is significantly extended (**Fig. 5** on the following page).

Galvanization began in early 1740s, during which the U.K. improved zinc-refining methods to enable mass production; however, France invented the galvanization method.

As described previously, iron tends to turn to oxides in the air because that is a more-stable state. Iron oxides form on the surface of steel materials before they reach the coating process, and they make it difficult for molten zinc to adhere to the materials. Consequently, a new flux method (post-process coating method) was invented in 1837. In this method, flux (salt) is applied to the surface of steel materials, and then they are immersed into molten zinc. This is a prototype of the current hot-galvanizing method. However, this method was difficult to apply to continuous production, so later, a new method was developed. In the method, rolled coils are continuously heated at high temperatures so as to reduce them with hydrogen to obtain a clean surface. This Sendzimir method (a continuous hot-galvanizing method), invented in 1931, revolutionized hot dipping. Nippon Steel Corporation introduced this coating method in 1953 and 1954.[4)]

2.4 Chemical treatment

As described previously, zinc is used as a coating to prevent the iron from rusting because zinc is easier to melt and has greater tendency to become ionic compared to iron. However, zinc also rusts (as white rust) if left untreated, as is the case with iron. Therefore, a chemical treatment is applied to the surface of zinc coatings to prevent it from rusting.

Among various treatment types, chromate coating was one that was most-frequently used and found useful. Thin chromate passivation films have high corrosion resistance and an excellent self-restoration property. A chromate film is an amorphous hydrous oxide, and its basic components are water-soluble hexavalent chromium and water-insoluble trivalent chromium.

This chromate treatment has been widely used for over the past half-century. During the course of this, in addition to the aim of preventing white rust to simply lengthen the service life of galvanization, various functions have been added. These include fingerprint-

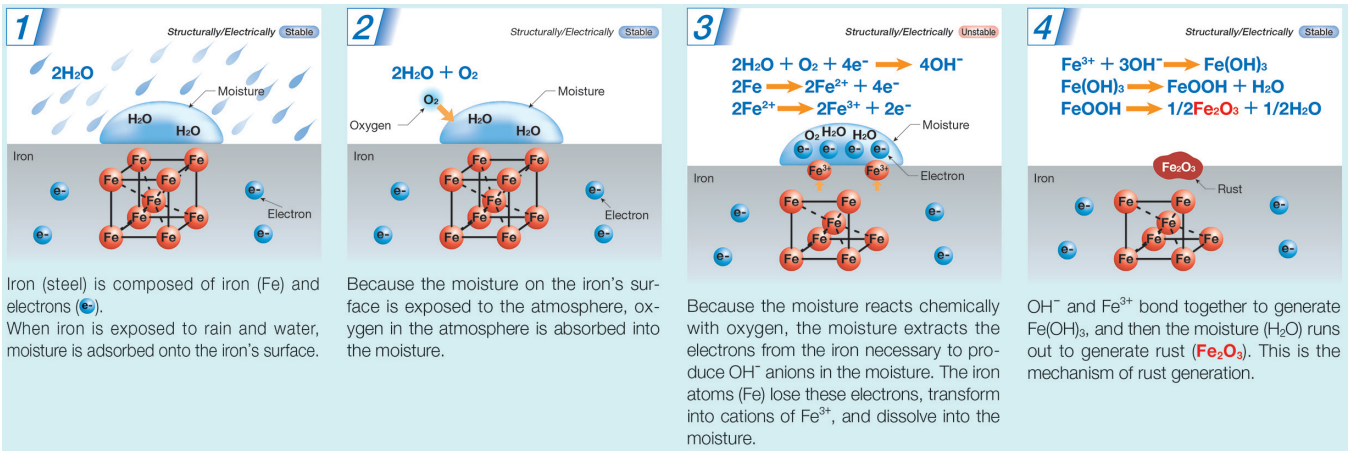

Fig. 2 Red rust is actually a comfortable state for iron

proof (prevents fingerprints from adhering), a sliding property to make the surface more slippery (which makes it easier to process the sheets), and high paint application property that improves adhesion with paints.

However, current environmental regulations caused a movement toward chromate treatment. Examples are RoHS (enforced in 2006 by the EU), which restricts the use of certain hazardous substances that damage humans and the environment, and REACH regulations (enforced in 2007 by the EU). Both are now global environmental regulation standards. They were repeatedly revised, and hexavalent chromium was included in the restricted substances. Accordingly, manufacturers urgently developed new, environmentally friendly chemical treatment, and, at present, in the automobile, electrical machinery, and container and package sectors, in particular, chromate-free films are used in place of conventional chromate films.

When the aforementioned pizza discussion is used as an example, the sauce to be applied to the pizza dough was changed to olive, tomato, and basil that were cultivated in an environmentally friendly way. Such a trend is quickly spreading, as people are becoming more sensitive to environmental concerns. Currently, not only in the automobile and electrical machinery sectors but also in other various sectors, environmental awareness has increased and is taking root.

2.5 Pre-painted steel sheets

Some customers apply various paints after they have processed steel sheets to parts in order to add surface design, more corrosion resistance, and other functionality. They voiced needs for the omission of their own painting process and for higher productivity.

Nippon Steel thus developed its pre-painted steel sheet, the VIEWKOTE™, for which various paints that we have developed on our own and base steel sheets are combined, and we finish the painting at our factories. Using epoch-making painting equipment (e.g., a curtain flow coater), we provide various improvement effects to satisfy the various needs of many customers.

2.6 Higher corrosion resistance

Allow me to go back to talking about coating here.

Galvanization succeeded in extending the service life of iron, but as time goes by, there were more needs for higher durability. Accordingly, to further enhance corrosion resistance in order to extend the service life of steel sheets themselves, we developed various coating types: Molten zinc-5%Al alloy coating (1972) for which 5% of aluminum (Al) was added to zinc (Zn) as a coating component and GALVALUME STEEL SHEET™ (1982) for which the content of Al was increased to 55%, satisfying needs for longer service life.

In 2000, approximately 20 years after that, we developed a line of completely new highly corrosion-resistant coated steel sheets for which the base was zinc (Zn) and where aluminum (Al) and magnesium (Mg) were added (i.e., a ternary system coating): Nisshin Steel Co., Ltd. (at that time) commercialized ZAM™ (Zn-6%Al-3%Mg), while Nippon Steel (at that time) put SuperDyma™ (Zn-11%Al-3%Mg) on the market; this happened one after another. Both products have been adopted in a wide variety of sectors, such as construction materials, automobiles, home appliances, and industrial

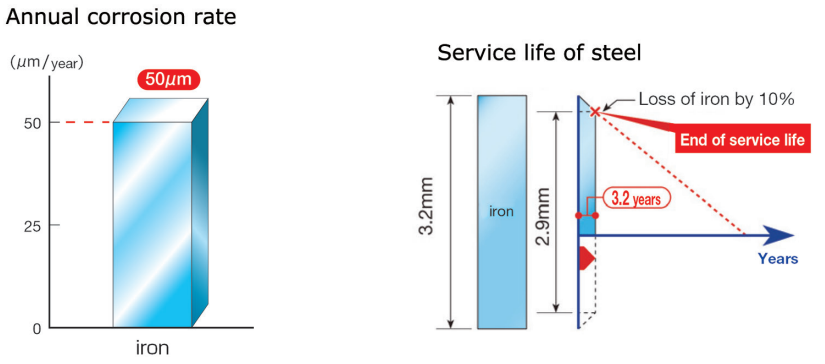

Fig. 3 Iron without treatment quickly rusts

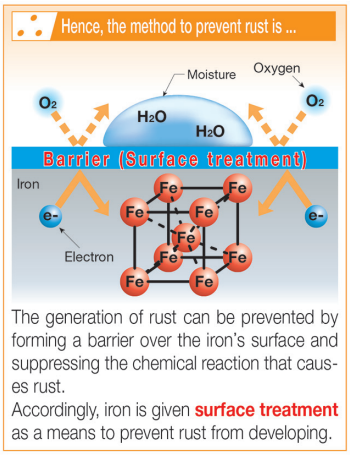

Fig. 4 How can rust be prevented?

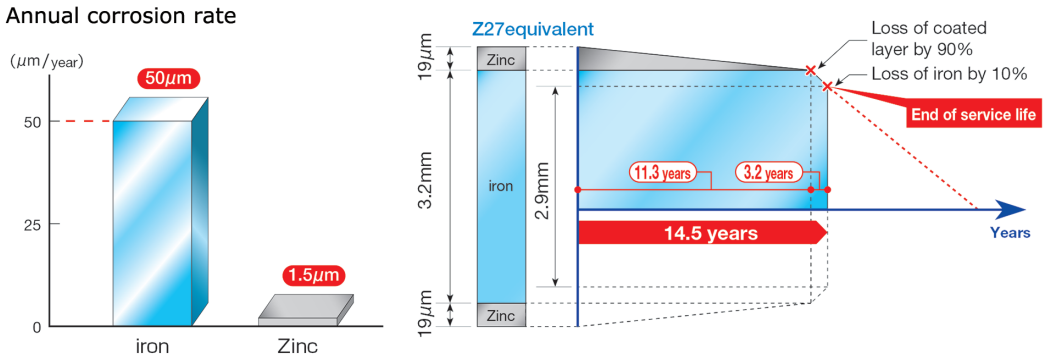

Fig. 5 Galvanization extends the service life

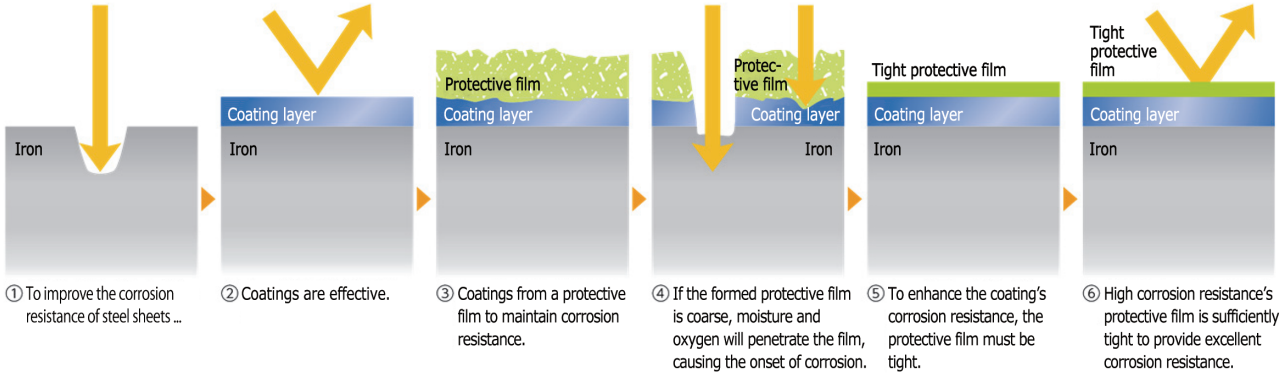

Fig. 6 Mechanism of the trick to prevent the surface of iron from rusting

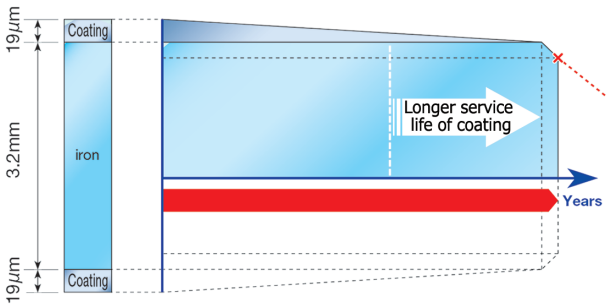

Fig. 7 Longer service life of coating extends the service life of iron

machinery (the accumulated quantity sold in and outside Japan as of 2021 was approximately 15 million tons). These are now standard types of highly corrosion-resistant coated steel sheets (**Figs. 6** and **7**).

2.7 Utilization and processing technologies

The main applications and needs for which these highly corrosion-resistant coated steel sheets have been used are as follows: to increase corrosion resistance because conventional coated steel sheets were insufficient; cost and construction period reduction through the omission of certain manufacturing processes; and switching from materials for post-process coating to reduce environmental stress.

However, for the latter, when sheets are processed to parts and products, the coatings disappear at the cut or welded sections, and the base iron of the steel sheets is exposed, so rust may form in the early stage. SuperDyma and ZAM have a special effect: the coating component around the cut or welded section dissolves to form fine protection films that will cover the rusted sections within several months (**Fig. 8** on the following page). However, even when customers understood that the rust would be eventually covered, some were reluctant to accept it, so they could not switch from other materials for post-process coating.

To eliminate the issue and to ease customer concerns, Nippon Steel has been developing and provides various utilization and processing technologies that allow customers to use highly corrosion-resistant coated steel sheets efficiently, i.e., for repair paints for cut sections, welding materials, welding methods, and bonding methods without involving welding.

Thanks to these effects, various customers switched from materials for post-process coating, but some customers still dislike rust formed in the early stage. That is our remaining one task.

3 The Current State

3.1 Papers introduced in this Technical Report

You have now glimpsed into the history of steel/iron and the development of technologies for steel sheets. New needs appear following evolution made to satisfy uninterrupted social needs. Now, allow me to introduce our cutting-edge research, technologies, and development as targeted by this special issue.

Although details will be left to the Technical Review and Technical Reports on the following pages, the matrix below shows which technology satisfies which new need in what way (improvement) (**Table 1**).

Firstly, the main new needs (on the right section of the table) can be broadly divided into material properties, environmental performance, and the performance of processed goods. The material properties can be further divided into corrosion resistance, surface design, and functionality.

The improvements that satisfy the needs can be organized as surface treatment (e.g., coating and chemical treatment/painting) and improvement proposals (e.g., utilization and processing technology and shape proposal).

When comparing the technologies to be introduced in this paper to the aforementioned "pizza," the main item is not the dough (the steel sheets) but is the sauce and toppings (e.g., coating and chemical treatment), as well as the cooking method. If you read the papers while keeping this in mind, the details will be easier to understand.

I will more deeply describe the technologies below for each theme.

3.2 Further enhancement of corrosion resistance

In measures for national resilience and aged social infrastructure, which are urgent tasks at present, there are demands for higher durability even in severe environments. In such civil engineering and social infrastructure sectors, post-process coated and post-process painted materials are generally used. And now there are more needs for much-longer service life. To satisfy such needs, Nippon Steel became the first manufacturer in the world to commercialize ultra-high-corrosion-resistant coated steel sheets. The new material, the ZEXEED™ (Zn-19%Al-6%Mg-Si) (Report 13), has ultimate corrosion resistance. (Our testing confirmed that the corrosion resistance of a flat section is approximately two times that of conventional

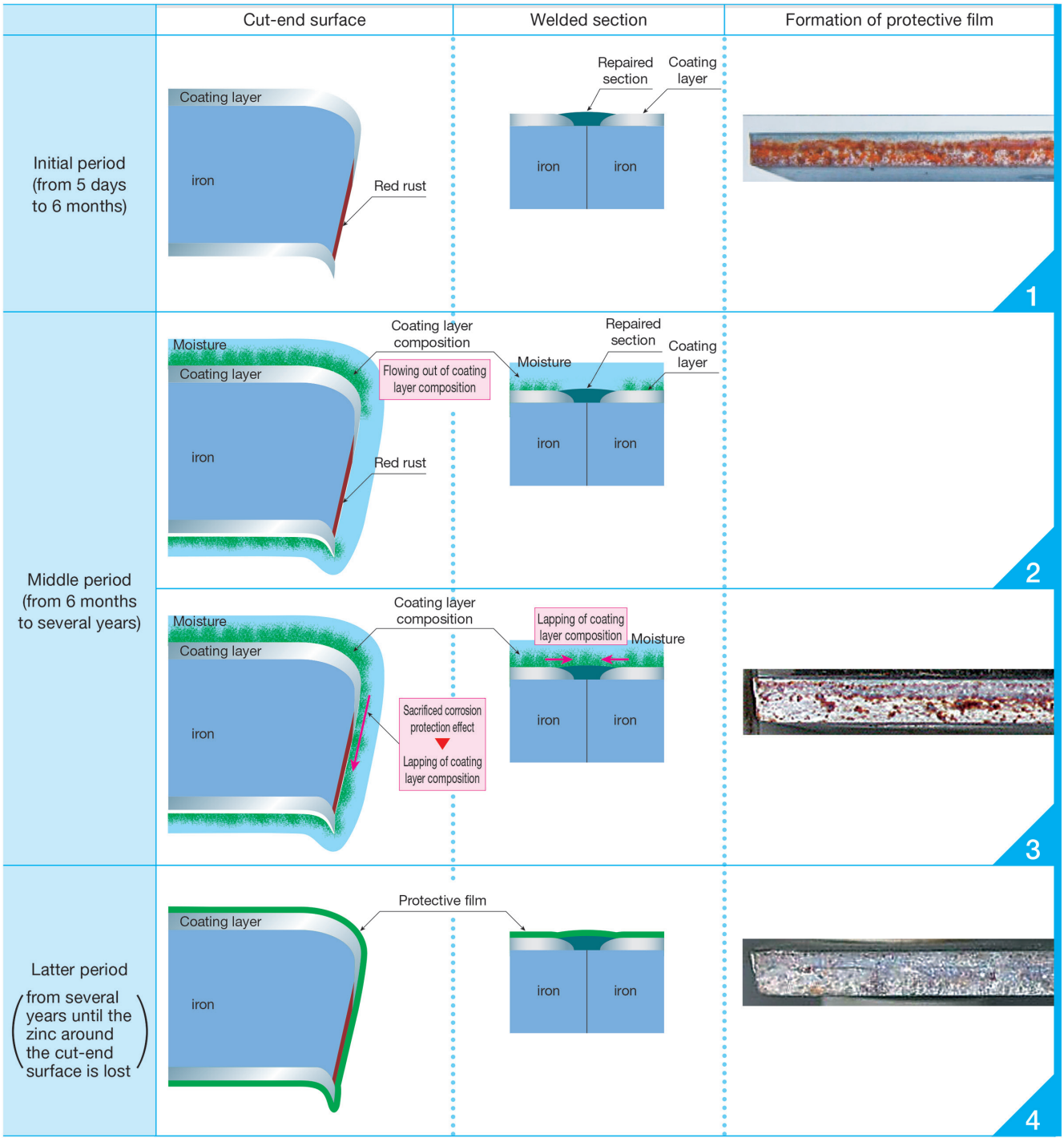

Fig. 8 Cut and welded sections change as time passes

highly corrosion-resistant coated steel sheets and approximately 10 times that of hot-galvanized steel sheet GI.)

In addition, there have also been needs for higher durability for the aforementioned Galvalume steel sheets, many of which are used in roofing and outer walls, as is the case with the aforementioned sheet types. Accordingly, Nippon Steel, Nippon Steel Coated Sheet Corporation, and BlueScope Steel Limited in Australia have worked together to develop the SGL™ 55%Al-Zn-2%Mg-Si alloy-coated steel sheet. We manufacture and sell SGL and pre-painted SGL, which has SGL painted onto the surface (Report 12).

Starting from galvanized steel sheets, steel sheets have evolved into these ultimate materials. Currently, excellent corrosion resistance extends the service life of various products. It is expected that this can contribute to life cycle cost reduction through manufacturing process omission and labor savings, as required in line with a decrease in labor populations becoming more and more of a concern while also making the daily lives of people in the future more affluent.

Table 1 Steel sheet types that this Technical Report handles

Click here to see the steel sheet catalogue.

Nippon Steel Technical Report No. 129 Special Issue on Steel Sheets for a Comfortable Life		Improvement ways and sections			Main new needs				
		Surface treatment		Improvement proposal	Material properties			Environmental performance	Performance of processed goods
No	Title	Coating	Chemical treatment and painting	Utilization and processing technology and shape proposal	Corrosion resistance	Surface design	Functionality	Environment-friendliness	Processing and shape
5	Electro Galvanized Steel Sheet with Hairline-like Appearance "FeLuce™ "	FeLuce™				FeLuce™			
6	Cockroach Repellent Steel Sheet, Anti-Virus Steel Sheet		Insect repellent/ Antiviral				Insect repellent/ Antiviral		
7	Proposal of New Functional Prepainted Steel Sheets Utilizing the Color Tone of the Undercoat Film		Functional VIEWKOTE™				Functional VIEWKOTE™		
8	Chromate-free Galvanized Steel Sheet with Spangle Texture	Chromate-free galvanized steel sheet with spangle texture				Chromate-free galvanized steel sheet with spangle texture			
9	Development of Chromate-free Treatment QC for Hot Dip Galvanized Steel Sheet		QC					QC	
10	Development of Chromate-free Treatment QA with High Bonding Strength		QA				QA		
11	SuperDyma™ Crystal	SD™ Crystal				SD™ Crystal			
12	"55%Al-Zn-2%Mg-1.6%Si Alloy Hot-dip Coated Steel Sheet SGL™ " and "Pre-painted SGL" for Building Materials	SGL™ Pre-painted SGL	Pre-painted SGL		SGL™ Pre-painted SGL	Pre-painted SGL			
13	New Corrosion Resistant Coated Steel "ZEXEED™ "	ZEXEED™			ZEXEED™				
14	Chromate-free Tinplate (EZP™)		EZP™					EZP™	
15	Cutting Technologies to Improve Early Corrosion Resistance on the Cut Edge Surface of a Zn Alloy Coated Steel Sheet			Solution to improve the corrosion resistance on the cut edge surface					Solution to improve the corrosion resistance on the cut edge surface
16	"Katachi" Solution – Five Approaches for Structure Weight Reduction and Some Examples –			"Katachi" Solution					"Katachi" Solution

Note: Clicking underlined letters brings you to the applicable report or website.

3.3 New environmentally friendly chemical treatment

As described previously, more chromate-free chemical treatment is applied to the surface of coatings with automobiles and electrical machinery, as a start. Nippon Steel has developed and offers various products in a way that leads the trends.

One such product is chromate-free tinplate EZP™ (Report 14). Tinplates are steel sheets coated with tin and used as materials for containers, such as for food, beverages, and general cans, all around the world. Tinplates are an environmentally friendly material with a high recycling rate. On the surface of tinplates, usually trivalent chromate is used as a film because it is acceptable from aspects of food safety. Nippon Steel, ahead of the limitation on the use of hexavalent chromium in 2024 as specified in the REACH regulations, has developed technologies for improving the work environment by disusing chemical substances including chromium in the manufacturing processes.

In addition, as people's awareness of the environment has been rising in recent years, there are increasing social needs for reducing the use of substances that damage the environment in the construction material sector in Japan as well. JIS standards for steel products now include more requirements for chromate-free surface-treated steel sheets to be used as construction materials. The Official Notice issued in June 2017 already specified the disuse of chromate for some products, and when the JIS standards are revised next time, applicable products are expected to be more expanded.

In order to cope with such social changes appropriately and quickly, we have developed the new QC chromate-free treatment (Report 9) for hot-galvanized steel sheets, used for various applications, and we started supplying this treatment to customers that are heavily considering the environment in their operations.

3.4 Surface design on coatings

To prevent rust, the surface of iron is coated. As described above, the representative method is galvanization. The coatings themselves are metal, so actually the surface is metallically glossy, and that is very beautiful.

Nippon Steel considered that, if we were going to coat steel sheets, we should make the most of the coatings; we should rather add beautiful design to the surface to enhance the designability and noticeability. We developed and commercialized many such products. I will introduce some.

Firstly, I would like to introduce an electro-galvanized steel sheet with hairline-like appearance; we call it the FeLuce™ (Report 5). This steel sheeting, with excellent design, is manufactured as follows: Zinc and nickel are applied to create corrosion resistance, while, on this alloy coating layer, hairline-like patterns are directly formed using a grinding brush. Light coatings of two colors (transparent and black) of clear resin, which imbues fingerprint-proof and

chemical-proof functions, are then applied on top. This revolutionary product has realized functionality while making the best of beautiful surface design, which is characteristic of metal materials. Currently, we are proposing this product for various applications, such as home appliances, industrial machinery, steel furniture, and interior construction materials, so you will eventually see more of this in the near future in terms of finished products.

The next product is Spangle Zinc™, which is an environmentally friendly, chromate-free, galvanized steel sheet with a spangle texture (Report 8). Nippon Steel also provides hot-galvanized steel sheets a with regular spangle texture (with flower patterns). These pattens form when zinc is melted at high temperatures in the coating process and then cooled upon contact with the steel sheet, then crystalizing. The even beautiful design is favorable, and the product is often used for air conditioner ducts in buildings or other similar applications. However, the flower patterns used to be developed by adding lead, etc., so Nippon Steel, focusing on environmental measures, disused lead. In addition, we further studied this chemical treatment, and this time, we succeeded in developing chromate-free films that have the same appearance, corrosion resistance, and workability as before, offering Spangle Zinc as a new chromate-free and lead-free environmentally friendly product.

The last product to introduce is SuperDyma™ Crystal (Report 11). SuperDyma has been often used in the overseas highly corrosion-resistant coating market, but imitations and fakes started appearing. We needed to figure out a way to clearly show that customers' products were using genuine SuperDyma so as to maintain and enhance the brand values of SuperDyma and the customer products that use SuperDyma. Therefore, Nippon Steel controlled the coating structure of SuperDyma so as to change the state of the gloss of crystals from part to part, such that letters appear like a transparency. In addition, a blue chemical treatment is applied over top. This combination of technologies differentiates SuperDyma from the imitations.

3.5 Adding functions to chemical treatment and painting

We added new functions to chemical treatment and painting to be applied to the surface of coatings so as to enhance the performance of steel sheets. We offer some such products.

One is a chromate-free treatment QA with high bonding strength (Report 10). As described previously, when steel sheets are welded, the coatings at the welded sections disappear, so repair for preventing rust is required. In addition, there are concerns about fumes released during welding and for poor welds from the viewpoint of quality. Consequently, steel sheets are more often bonded in place of welding these days.

To satisfy such new needs, we have developed special base films that have high strength of bonding with the surface of steel sheets and for which the adhesiveness and corrosion resistance can be retained for an extended period of time, and we are now supplying them.

Another is a new functional pre-painted steel sheet utilizing the color tone of the undercoat film (Report 7). Applying colorless, transparent films with various functions to the surface of the aforementioned VIEWKOTE produces high-value-added products that satisfy various needs appropriately while making the most of the design of the undercoat. An example is an oil-repellent/water-repellent type that makes maintenance easier, a retroreflection type that is highly noticeable in dark places and thus useful for safety measures, and a thermochromic type for which the color changes depending on the temperature, so as to show danger due to by high or low temperatures, in order to raise user attention.

To respond to an increasing awareness of sanitation, we have also developed our Cockroach Repellent Steel Sheet, which repels insect pests, and our Anti-Virus Steel Sheet, which features an antiviral property via visible-light responsive photocatalysts (Report 6).

Our Cockroach Repellent Steel Sheet, having our workability and corrosion resistance, includes an insect-repelling component in its surface treatment that cockroaches and other disease-carrying insects dislike, and the sheeting prevents such insects from coming into contact with it (repellency). This type is mainly used for home appliances in kitchens.

In addition, our Anti-Virus Steel Sheets feature a hybrid function that reveals an antiviral effect under illuminance at the level of indoor lighting and also even in dark areas. Naturally, this product retains conventional functions, such as workability and fingerprint-proof properties, as its quality level. Accordingly, for example, adding this anti-virus effect to the aforementioned FeLuce steel sheet, which has excellent surface design, brings the expectation that the sheets can be adopted for office furniture, interiors of public facilities, and home appliances (Anti-Virus Steel Sheets series).

3.6 Using our steel sheets efficiently

I have introduced the Nippon Steel's cutting-edge technologies related to steel sheets so far. Actually, there are some customers who do not quite understand how to use such materials. In order to satisfy such customer needs, Nippon Steel has been doing many studies on methods of processing and on ways of using materials and proposing utilization and processing technologies that can maximize the performance of each product for our customers.

One example is a solution to improve corrosion resistance on a cut edge surface (Report 15).

As described above, when hot-galvanized steel sheets are cut, rust can unavoidably form at the cut sections in the early stage even if the material is ZEXEED or another highly corrosion-resistant coating, unlike materials for post-process coating for which coating is applied after cutting. This is a remaining issue when customers select materials.

Accordingly, we are working to solve this issue by figuring out a way to cut a steel sheet such that the components of the coating provided on the surface of the steel sheet go round and cover the cut section. This can be likened to changing the cutting method of a food material to make it more delicious. We have been technically studying various cutting methods, for example, cutting a steel sheet so as to provide a slant on the cut cross-section and cutting involving well-designed shear dies.

Moreover, we also propose shapes (structures) conforming to what items made from steel sheets "should be" (i.e., "recipes" and "cooking procedures"). A solution summarizing such proposals is our "Katachi" Solution—five approaches for the weight reduction of structures, along with some examples (Report 16).

When taking the body of a living thing as an example, in the products, equipment, and buildings of customers, iron is mainly used as the bones, skin, and parts that support and secure various internal organs. A living thing designs its body so as to fit itself. Similarly, many of things around you have been designed in a way appropriate to them. However, design principles that had been standardized and generalized have been applied to some of them without thought in some cases. They may not be styles of today and could be a burden on a human body.

Fig. 9 Three ecos and innovative technology development[5)]

The current trend is light, strong bodies (slim but muscular), so our goal is to find and design a structure that can reduce weight while retaining performance. In recent muscular workouts and dieting, the body and work style of each person are scientifically analyzed to determine an appropriate goal, and the processes to that goal are closely determined and followed up on, in place of mere muscular workouts and dieting. Similarly, to find optimum shape, various conditions (e.g., raw materials, shapes, and loads) need to be considered and incorporated with variables, and multiple designs need to be devised so as to verify the effects.

Nippon Steel has been organizing and standardizing improvement perspectives for steel sheets by drawing on our steel structure design technologies as accumulated in the construction sector over many years. We also have established an organizational structure that allows us to propose such improvement perspectives as solutions for using steel materials focusing on shape, contributing to various customers' diverse "recipes."

3.7 Understanding and satisfying needs

As described above, Nippon Steel understands the many needs of various types of people and develops new technologies that satisfy such needs, making every effort to realize better and more-comfortable living through steel sheets.

You may have noticed that we have been advancing to a new, big expectation that your safe and secure living can continue forever.

Nippon Steel has been challenging itself hard to develop products that have longer service life and that can omit certain manufacturing processes, along with developing technologies for utilizing such products; these efforts are designed to realize better and more-comfortable living, i.e., an environmentally friendly, sustainable society.

4 From Now Onward

4.1 New need for environmental friendliness

Now, allow me to look back on what I have introduced so far.

People started obtaining iron approximately 4000 years ago. Since then, iron has evolved so as to satisfy the various needs of people and is widely used everywhere. It can be said that your living has advanced with iron, becoming more affluent with every step. However, as people's living has been becoming more convenient and comfortable, the influence of global warming and climate change on the environment has become a problem.

Now, a new need is breaking on top of us intensively and violently as an enormous wave, i.e., environmental friendliness toward carbon neutrality, which is said to be the biggest social and economic change since the Industrial Revolution. People have already started working for the UN SDGs, which are worldwide goals toward a sustainable society.

Fig. 10 Make Our Earth Green

4.2 Nippon Steel's green management

Nippon Steel has been actively working to produce environmentally friendly products and to save energy by promoting green management involving the following four main concepts: (1) Eco Process: The way we manufacture is "eco-friendly," (2) Eco Products: What we produce is "eco-friendly," and (3) Eco Solution: Sharing our "eco-solutions," which are three principles of "eco" under our basic environmental policies, as well as (4) Innovative Technology Development. Among those, what we put our energy into most is "Innovative Technology Development: Innovation" (**Fig. 9**).[6)]

When producing iron in conventional processes, CO_2 is unavoidably emitted.

In order to produce iron without releasing CO_2, the very processes to produce iron, which have continued for several 1000s of years, need to be dramatically changed. That is an unprecedented task toward realizing technologies that humans have not been able to reach.

To make the earth comfortable for not only humans but for all living things, Nippon Steel determined a long-term vision, "Nippon Steel Carbon Neutral Vision 2050," to be carbon neutral by 2050, with clear goals. We have been working hard to develop the following three ultra-innovative technologies: Direct reduction with 100% hydrogen; hydrogen-reduction ironmaking via the blast-furnace method; and using the electric furnace method to produce steel materials that have quality that is the same as that produced via the blast-furnace method. We have also been working to combine those technologies from diversified perspectives (i.e., "Steel and hydrogen will change our planet and our future") (**Fig. 10**).

However, it takes a little longer to establish such technologies and deliver products to customers whatever we may do. Is there no other choice but to wait without doing anything until then? People cannot stand it. Therefore, until when such a new world is realized,

we are pursuing world-best technologies and manufacturing skills while fully using our knowledge and figuring out new ways to do things. We are putting our energy into satisfying needs appropriately with our technologies and products.

4.3 What we can do now

What kinds of improvements are there then? Let's think about it together.

You have probably heard the term "3Rs." "3Rs" is an abbreviation for reduce, reuse, and recycle, and it has been a long time since the term took root in your living. The term still carries hints on how to use iron efficiently and on the direction that we should take from now on.

Firstly, regarding recycling, recyclability is one characteristic that is a pride of iron. Iron has very convenient and excellent characteristics such that after use, iron can be recycled again and again without impairing quality and can be turned to any shape. Using iron efficiently and making full use of it work well to preserve the environment.

The next term is "reduce." The CO_2 emissions per unit when iron is produced is smaller compared to other materials, so using iron can reduce environmental stress. In addition, for example, if steel sheets are used and when we apply coating and painting to such via our manufacturing lines, that brings several reductions: downstream processes (e.g., post-process coating and post-process painting), and work for such processes can be naturally reduced while CO_2 emissions throughout entire manufacturing processes can also be reduced. Furthermore, switching to highly corrosion-resistant coating such as ZEXEED from general galvanization can reduce the usage of zinc. Moreover, extending the service life of products themselves can put off replacement in the future, which can also work to reduce the materials and labor required for future replacement.

Lastly, society may be standing at a crossroads of complete reuse. There are several possible avenues for this: the main bodies or parts of used products are reused, and old frameworks are left untouched and used while only necessary sections are repaired and renovated to continue to use them, for example, like houses. Once the values of such usage are recognized and increased in the future and when systems are developed, designing products assuming reuse, which makes such usage possible, could accelerate. What is required for such usage is material with a long service life that can be repeatedly used. Expectations for iron also increase from this aspect.

4.4 Trends of the times

Allow me to see the trends of the times from the position of each consumer and business entity.

Consumers will actively use environmentally friendly products. They will select high-durability resource-saving products and will continue to use them carefully as long as possible by maintaining and repairing them. There are ways to think about this, assuming throwing away after one use; for example, "if broken, I can buy a new one" or "I can replace it." In addition to such ways of thinking, new awareness and living styles in which people select tough or replaceable products could rise. In addition to comfort for individuals, sustainability when taking the long view could be gradually incorporated into people's sense of values and judgment standards, and this could become more important, little by little.

New thinking is like thinking patterns when selecting food, as a familiar example. As times change, people's selections have changed from what they want to eat and what they like and other reasonable foods to healthy pesticide-free or organically grown farm products. In this new trend, people now tend to select environmentally friendly food products, if possible, considering the Earth and its future.

The perception of ourselves and people around us changes from "selecting environmentally friendly food products is cool" to "it is right" and then eventually to "it is essential." The speed of such change will increase rapidly. A new concept will rise.

This trend has influence on business entities as well on private consumption. Corporate activities for reducing damage to the global environment are becoming highly valued, and companies that have not been seriously working toward environmental preservation are losing support from society. The concept "it is essential" is coming closer, and thereby business entities must change their perspectives.

The manufacturing industry will shift as follows. Manufacturers will use the minimum necessary raw materials that are environmentally friendly as much as possible when designing and manufacturing products. They will also improve and extend after-sales services (inspection, maintenance, and repair) to encourage customers to use their products for an extended period of time. And they will recycle used products efficiently. In that case, what needs are there regarding the quality of steel sheets? The answer is long-service life (durability) so as to stand up to repeated use. In addition, materials for which additional processing is easy (for example, easy-to-remove non-welding joining in place of welding and bonding) and recyclable materials can be selected. As a material that matches the new design philosophy, expectations for iron could increase, and there may be more need for iron.

This also applies to public property, such as infrastructure and buildings. You have seen that equipment also ages as time passes, as is the case with humans and things, and that replacing aged equipment and national resilience have become urgent tasks. Also, now you know that long service life brings safety and reduces future costs, which in turn reduces CO_2 emissions. To leave a bright future for your descendants, it is necessary to use the latest innovative technologies to realize longer service life and to eliminate future concerns as much and as quickly as possible.

What can you do now and in the future? Behave while considering society and the whole, in place of yourself and the individual. The time where such attitudes are highly valued will surely come.

4.5 Iron's potential

As mentioned previously, when iron is produced, the emissions intensity of greenhouse gases is low, and substantially, all the quantity is recycled, so iron is a sustainable material that reduces new greenhouse gas emissions. Life cycle assessment (LCA) is used to measure impact on environments throughout all processes, from production to after the use. From this aspect, the potential of iron, which is an environmentally friendly material, is unknown and infinite.

To maximize potential, we will use our ability in developing technologies and producing high-value-added products in a stable way in order to further deepen comprehensive activities with customers in and outside Japan. We will further promote research, development, and commercialization in each sector to satisfy needs for new product development that we come to understand in the course of such activities. We will also make the most of such advanced characteristics within the entire group and will form the shape of what environmentally friendly materials that can continue to protect

society should be.

Nippon Steel will contribute to realizing more-affluent living for people in the future and a safe and secure society, while establishing an energy-saving, low-environmental-stress, recycling-oriented society as well.

5 Conclusion

In this paper, I simplified the details as much as possible and tried to use easy-to-picture expressions so that people not familiar with iron that are thinking to learn more about it can be interested in iron even just a little more, thinking that iron is becoming more familiar, in addition to people who know iron well.

Regular and technological papers, which are the essentials of this Technical Report, will be shown below. Lastly, allow me to use another familiar thing as an example to explain iron. That is a cocktail.

5.1 Is making ironmaking a cocktail?

Are the processes used to make iron like those to make a cocktail.[7)]

To make iron, raw materials (e.g., iron ore) and reducing agent (e.g., coal) are put into a blast furnace, which is type of equipment that looks like a shaker, and then these items are mixed and melted at high temperatures. The processes are very like shaking a shaker containing liquor, liqueur, juice, and ice. However, the size of the equipment and the temperatures used are completely different from making a cocktail. The height of general blast furnaces in Japan is 30 m, while the girth is 50 m, and the temperature of discharged iron is approximately 1500°C (**Fig. 11**).

However, actually, the produced iron is not so "tasty" without further treatment. Some components in the raw materials (base) cancel out the "flavor" of each other, and often the produced cocktail, which should be good-tasting, cannot become a popular taste.

Accordingly, in the steelmaking process, a converter that looks like a mixing glass is used. The iron is put into the equipment, and oxygen is blown in to burn unnecessary items while stirring; the "good-tasting" supernatant fluid is taken to prepare an undiluted solution for a "cocktail." What is produced through these processes is steel, which is often used as a base material in various industries (strictly speaking, iron is different from steel).

However, the "cocktail" thus obtained cannot be offered to a customer because it is an undiluted solution. Accordingly, the next step is to pour the undiluted solution into a glass to give shape to the liquid.

There are various types of glasses for cocktails, such as a cocktail glass, old-fashioned glass, and Collins glass, that match each style of cocktail. Iron can also be provided in various shape types. The manufacturing processes vary between types, so there are various types of mills and systems used. Thus, we are ready for producing and offering various iron types depending on the need, preference, application, and style of customers, as is the case with the wheat described further above.

The last step is decoration. The taste (quality and functions) of a cocktail will be further prominent by taking additional labor to make it look better (post-treatment). Representative things for cocktails are fruits and lemon peels, which are used to decorate the edges of glasses brilliantly. Meanwhile, coating, chemical treatment, and painting are applied to the surface of steel sheets as introduced in this paper, and these correspond to the "fruits." After finishing by rust-proofing or improving the surface design, the cocktail is eventually ready for "serving." It is like pizza.

(The cutting-edge technologies to be introduced in this paper are the fruits of our efforts for the very last stage of labor.)

As additional information, some customers like to tell you their preferences or feelings at the time of ordering, so that you can prepare something that matches those, instead of ordering standard cocktails, such as a daiquiri and martini. In such a case, we, as professionals, create a recipe (product) that matches the customer's request from the technologies and materials at hand and also propose the best way of drinking the cocktail. This is sometimes referred to as "solution sales," and if you are pleased at the "solution," we are very happy.

However, even when we can prepare a new delicious cocktail, if it does not fit the needs of many customers and the trends of the times, it results in a one-off product and will not be popular in society as a standard product. Therefore, we always work to understand customer needs through conversation, and we pay attention so as to avoid our development from becoming self-satisfied.

Interestingly, as is the case with cocktails, even if the same recipe and tools are used to produce iron, the taste could be slightly different depending on minor adjustments (e.g., the blending of the raw materials and cooking time), skills of the bartender (steelmakers), and the atmosphere of the bar (e.g., temperature and humidity).

Fig. 11 Is ironmaking like preparing cocktails?

Some customers attach importance to cost performance and can tolerate (swallow) a slight difference, but some that attach importance to taste do not allow our overly optimistic view. Skilled workers are always working with an attitude that is like sword fighting—they battle it out to ensure that customers are satisfied with both quality and cost.

Actually, not only the bartender that shakes the shakers in front of customers makes cocktails. Other important tasks involve ordering and storing new materials for insufficient stock considering when what customers order what and thinking and instructing the sequence to handle orders when the bar is crowded.

This also applies to ironmaking. As an industrial product that support customers' production, stable quality and delivery schedules should be secured. To that end, all staff should work in cooperation throughout all processes, from research & development to the procurement of raw materials and fuels, management of the operation of factories to produce products, management of technologies and quality, progress management, delivery, and transportation.

If even one of these is lost, the necessary numbers of products that customers require cannot be delivered to the requested locations at the requested time. Accordingly, all staff work hard as one body, every day.

Customers then evaluate the appearance and atmosphere of the bar, the conversation with the bartender, and the prices comprehensively, to say nothing of the taste of the cocktails, and they determine each time whether they will come again. I wish that our daily efforts as accumulated reach you and that you feel like coming again.

So, what do you think? Ironmaking is surprisingly like preparing cocktails, isn't it?

When you eat pizza or enjoy drinking in the future, if you remember this essay and consider the long developmental history of iron, the various needs that served as starting points, the people that steadfastly repeated trial & error in development and manufacturing to satisfy such needs to form the "now," and ourselves, who have been working hard to create a better future, even a little, well… that makes me happy.

5.2 Conclusion

Nippon Steel has been always leading the times and "cutting open the future" by understanding the needs of society quickly and by satisfying them ahead of others. Our evolution never stops. Satisfying your needs involves pressure and delight. In our work, we have firm self-confidence and pride as employees of Nippon Steel. We want to continue to be your no.1, forever. Please rely on Nippon Steel in the future as well.

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