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Environment-friendly Steel Products for Home Electric Appliances and Power Industry Systems†

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Abstract:

JFE Steel's challenge to prevail the environment-friendly community proposes a variety of steel products with remarkable function for the purpose of environmental safety and energy saving. For example, steels without hazardous substances like lead or chromium (VI), and electrical steels for energy saving. Particularly, this article gives a short brief on the recent usage in the electrical industries leading an important role for our modern society.

1. Introduction

In Dec. 2002, the adopted important directives establishing future directions for home electric appliances. Directive 2002/96/EC, or WEEE (Waste Electric and Electronic Equipment), makes manufacturers responsible for designing and manufacturing products for easy disassembly and recycling, and assigns distributors the responsibility for creating the systems necessary for collection and recycling used products. Directive 2002/95/EC, or RoHS (Restriction of the Use of Certain Hazardous Substances in Electric and Electronic Equipment), bans the use of six substances including lead, hexavalent chromium, cadmium, and others.

Energy conservation programs and efforts to introduce oil-substitute energy source are also being implemented worldwide with an aim of reducing CO_2 emission, which is a main cause of global warming. For example, energy saving measures such as the 1W standby power regulation in the United States, regulations on power consumption by the top-runner system in Japan, and "Energy Star" and other energy conservation labeling systems have now been adopted in more than 37 countries.[1)]

Iron and steel products are used in a diverse range of applications in home electric appliances and power industry systems. The JFE Steel is actively contributing to the global environment by proposing Only 1 and No. 1 products in these respective applications. This paper presents main examples of recent environment-friendly products developed by JFE Steel.

2. Steel Sheets

2.1 Chromate-free Conversion Treatment Steel Sheets

2.1.1 Environmental problems related to coated steel sheets

Chromate treatment of Zn galvanized steel sheets is widely used as a low-cost rust-preventive process for

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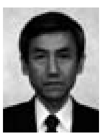

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suppressing white rust of Zn. In response to the rapidly increasing need for improved rust prevention and multi-functionality in materials since 1980s, many high performance coated steel sheets with an anti-fingerprinting property, paintability, lubrication property, designability and other properties have been developed, including dry-in-place chromate treated sheets and organic composite coated sheets with a chromate film and thin organic resin coating film (1–2 μm or under), and are now widely used in home electric appliances[2)].

However, with heightened environmental protection activities, there has also been an increasing trend to reduce the use of substances which place loads on the environment. In Europe, six substances (Pb, Cr (VI), Cd, Hg, etc.) which are commonly used in electric and electronic equipment have been designated in EU's Restriction of the Use of Certain Hazardous Substances (RoHS) Directive and will be banned effective July 2006. In Japan, major manufacturers of home electric appliances and OA equipment have adopted "Green Procurement" policies promoting the purchase of environment-friendly materials and products, and as part of these programs, are attempting to reduce the use/release of substances which place loads on the environment. In response to these trends, JFE Steel is accelerating the development and commercialization of chromate-free products.

2.1.2 Product line of chromate-free steel sheets

Against this background, JFE Steel has created a line of "Eco Frontier Coat" products, beginning with JN which offer the industry's No.1 quality and performance and is actively developing and commercializing environment-friendly coated steel sheets of various types (**Table 1**)[3-5)].

2.1.3 "Eco-Frontier Coat JN"

(1) Examples of Product Application

Eco Frontier Coat JN is a chromate-free anti-fingerprinting steel sheet with multiple functions including corrosion resistance (time to 5% white rust in salt spray test: 72–120 h), anti-fingerprinting property, electrical conductivity (grounding property), spot weldability and coatability. It is applied to the chassis and bottom plates of OA and AV equipment, internal plates of home electric appliances and similar products.

(2) Concept of Film Design

Increasing the thickness of an organic composite film generally improves corrosion resistance but reduces conductivity and weldability. To secure satisfactory conductivity, the film thickness must be of the 1–2 μm level or less. In the conventional chromate-free conversion treatment technique, the thickness of at least 3 μm was necessary to secure corrosion resistance, resulting the decrease in conductivity.

Table 1 Wide selection of chromate-free products

Type	Features	Main applications
JN Corrosion resistance*1	High conductivity and corrosion resistance Corrosion resistance after alkaline degreasing	OA, AV equipment chassis Copiers Computer cases Home appliance parts
JS Corrosion resistance*2		
JT Special coating	High paint adhesion (also suitable for powder paint applications)	Refrigerators Showcases
JW High lubrication	High lubricity	Oil stove tanks Oil fan heater bearings Motor covers
Z1 Black-colored	High heat absorption/radiation property	Electronic equipment parts Copier internal parts
JD High formability	Excellent formability Corrosion resistance after forming	Small motor cases

*1 Type with priority to electrical conductivity
*2 Type with priority to corrosion resistance

Proprietary element technologies developed by JFE for Eco Frontier Coat JN include (a) an organic resin coating film with an advanced barrier property and (b) an inorganic rust-preventive additive with a self-healing property in the organic resin film. By developing an organic composite film incorporating these unique technologies, JFE Steel realized high corrosion resistance with a thin film for the first time in the world, successfully satisfying the mutually-contradictory requirements of corrosion resistance and conductivity at a high level. This technology was put into industrial production in 1998.

(3) Quality and Performance

The following describes the outstanding features of Eco Frontier Coat JN:

(a) High corrosion resistance

Photo 1 shows the results of a test of unpainted corrosion resistance (appearance after 72 h salt spray test). The developed product showed no white rust and thus possesses satisfactory corrosion resistance which is equivalent to that of chromate-treated steel sheets.

(b) High corrosion resistance after alkali degreasing

After steel sheets are press-formed by the user, alkali degreasing is generally performed to remove surface oil and dirt. One problem with non-chromate chemical conversion treatments was a sharp decrease in corrosion resistance due to degradation of the coating film by this alkali degreasing process. Eco Frontier Coat JN shows virtually no deterioration in corrosion resistance after alkali degreasing, and maintains the same excel-

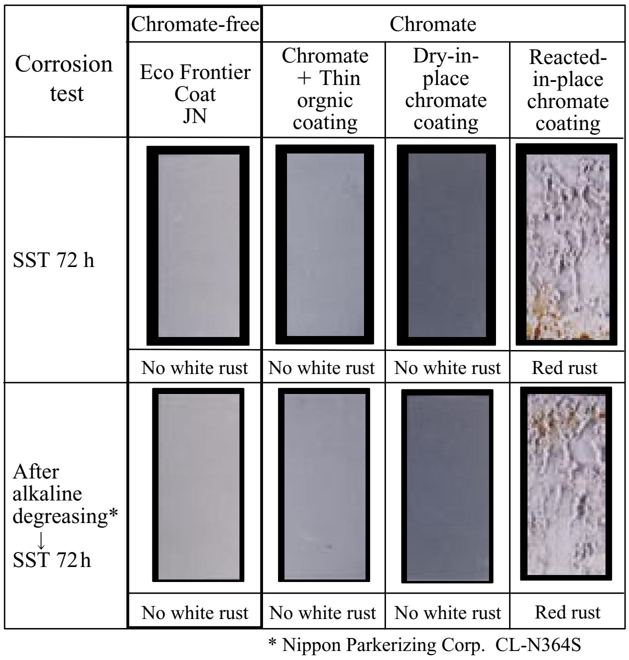

Photo 1 Corrosion resistance of various coated steel sheets

lent properties.

(c) High conductivity

Due to the thin organic composite coating film used for Eco Frontier Coat JN, it has high electrical conductivity and can be applied to OA and AV equipments which require high conductivity (grounding property).

As an outstanding multi-functional chromate-free steel sheet, Eco Frontier Coat JN also provides high performance in anti-fingerprinting, weldability and coating adhesion. This technology was awarded with the 2002 Technology Prize of the Surface Finishing Society of Japan.[5)] In the citation, the developed product received extremely high praise for uniqueness and technical progress, as "a high level of corrosion resistance was realized with a thin film that become possible by developing a high barrier property organic composite coating film, successfully meeting the mutually-contradictory requirements of corrosion resistance and conductivity/weldability at a high level," and for its actual results in industrial production where it "successfully realizes industrial production and has earned a high evaluation in the market (OA equipment makers and others)."

2.1.4 "Eco-Frontier Coat JD"

Eco Frontier Coat JD possesses high formability and corrosion resistance after forming, and was put into industrial production in 2003. This chromate-free coated steel sheet has the following distinctive features due to use of a special coating film:

(1) High Formability

Film peeling during forming is extremely slight, enabling use in deep drawing applications (small motor cases, etc.).

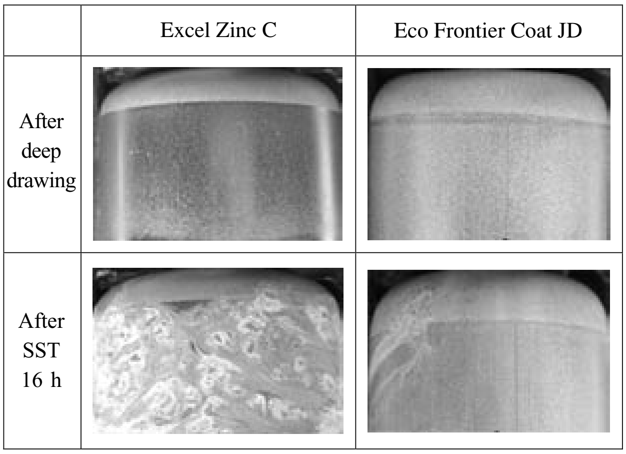

Photo 2 Appearances after deep drawing and SST for 16h

(2) High Corrosion Resistance after Forming

The corrosion resistance of deeply drawn Eco Frontier Coat JD is superior to that of the conventional, chromate-treated steel sheet (Excel Zinc C). The appearance of deeply drawn parts after a 16 h salt spray test is shown in **Photo 2**.

(3) High Conductivity

IT prevents electromagnetic wave leakage (noise prevention).

2.1.5 "Eco-Frontier Coat Z1 (Black-colored Steel Sheet)"

In black-colored steel sheets, an electrochemical black treatment film which possesses electrical conductivity and an anti-fingerprinting film with high corrosion resistance and conductivity are applied to a Zn-Ni coated base steel with excellent corrosion resistance. In response to the demand for chromate-free products, JFE Steel developed Eco Frontier Coat Z1, which absolutely contains no chromate, and began its industrial production in 2002. This chromate-free, black-colored steel sheet has the following distinctive features:

(1) Black of a Glossy and Deep Color Tone

This steel sheet meets the advanced requirements of optical parts and is also an optimum product for applications which require a beautiful appearance.

(2) High Conductivity

It prevents electromagnetic wave leakage and noise.

(3) High Corrosion Resistance

It allows the customer to omit painting.

(4) High Heat Absorption/Radiation Property

The Eco Frontier Coat Z1 gives a high thermal emissivity value of 0.90 (measured at wavelength of 5.8 μm), which is significantly larger than the value of 0.60 for ordinary electrogalvanized steel sheets measured under the same conditions. This property

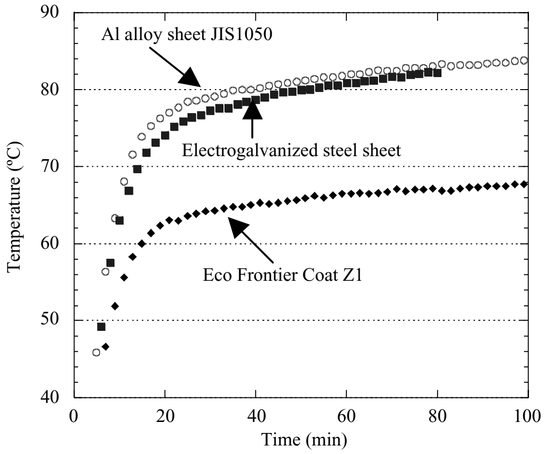

Fig. 1 Temperature increase inside a radiation tester

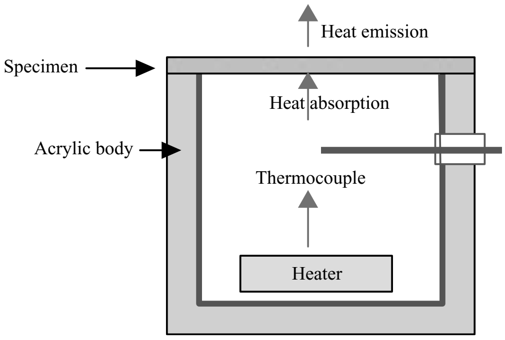

Fig. 2 Radiation performance tester

is useful in removing internal heat from an electric/electronic equipment, preventing abnormal temperature rise inside the case. The examples of measured result are shown in **Figs. 1** and **2**.

In the future, the use of black-colored steel sheet Eco Frontier Coat Z1 is expected to expand to the applications of heat absorption/radiation (computer-related equipments, car stereos), optical applications (copiers, televisions), and applications which omit the painting process.

2.2 Creation of New Product Value Using Material Utilization Technologies

2.2.1 Importance of material utilization technologies

With rising environmental needs such as green procurement and recycling/reuse as well as cost reduction needs accompanying more intense international competition, the requirements placed on material utilization technologies for steel sheets for electrical equipments have also become more diverse. For this reason, JFE Steel not only supplies materials, but also provides the most suitable support for optimum utilization of steel products based on many element technologies that have been cultivated in process development in the steel industry. The examples are presented in the following:


Photo 3 Example of drawing formability simulation

2.2.2 Optimum support for material utilization

(1) Evaluation of Product Properties
JFE Steel supports optimum design by evaluating structural rigidity, impact, temperature and other properties using numerical simulation technologies.

(2) Evaluation of Formability
JFE Steel performs simulations of shape optimization and die improvement by the method of CAE technologies, supporting shorter product development time and substantial reduction in development cost.

(3) Life Prediction (Corrosion Prediction)
JFE Steel provides support in selection of the optimum material for each part based on life prediction.

(4) Support for Recycling/Reuse
The importance of recycling and reuse has been advocated in recent years. JFE Steel is making positive efforts in this area, for example, by promoting steel sheets as an environment-friendly substitute for plastic. **Photo 3** shows an example of application of a steel sheet to a hard-to-form case part, which became possible with a high formability steel sheet.

These activities enable customers to achieve further reduction in development time and cost.

3. Electrical Steel Sheets

3.1 High Magnetic Flux Density Grain-oriented Electrical Steel Sheet for Low Noise Transformer Use “JGS”

Grain-oriented electrical steel sheet is a type of electrical sheet made of 3% Si-added steel, and is characterized by highly aligned grains in the {110}<001> orientation, or so-called the Goss orientation. Because of excellent magnetic properties in the rolling direction, grain-oriented electrical steel sheet is frequently used in the applications which require uni-directional magnetization, such as transformer cores.

With rising public demand for reduced transformer noise, low noise measures have been also required in

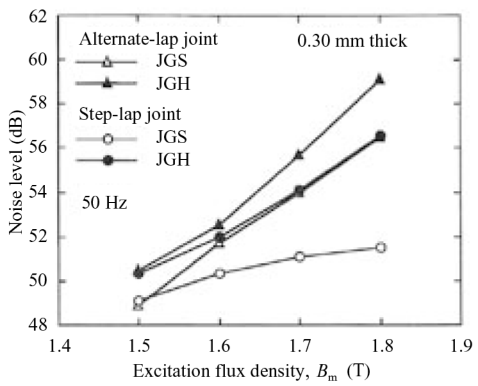

Fig. 3 Noise levels of model transformer cores made of 0.23 mm thick JGS and JGH sheets

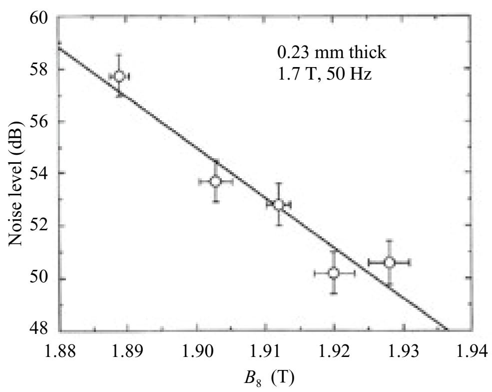

Fig. 4 Relation between noise level of step-lap model transformer core and B_8 value of core material

grain-oriented electrical steel sheet used as transformer core material. The main causes of noise in transformers are thought to be magnetostriction vibration generated in the interior of core material and magnetic vibration at core joints.[6] Of these factors, magnetostriction vibration, which is a material-related factor, occurs during alternating current excitation, corresponding to misorientation of grains from the ideal orientation. Since the high frequency range of this vibration is sensed as noise, increasing the degree of the grain alignment in the Goss orientation, in other words, increasing the material magnetic flux density B_8 (magnetic flux density at 800 A/m) is important for noise reduction.[7]

JFE Steel developed the grain-oriented electrical steel sheet JGS to reduce this type of transformer noise. As features, it realizes a high magnetic flux density, B_8 value of 1.92–1.93 T in the 0.23 mm–0.35 mm thick products.[8]

Figure 3 shows the noise in the model cores of stacked transformer using 30JGS105 (B_8:1.93 T) and 30JGH110 (B_8:1.90 T). In comparison with the conventional high magnetic flux density material JGH, the noise level is effectively reduced with JGS, by approximately 2 dB with an alternate-lap joint and 3 dB with a step-lap joint. The relationship between B_8 and noise in the model cores of stacked transformers in **Fig. 4** clearly shows that noise can be reduced with the increase in B_8.

3.2 Magnetic Domain-refined, Grain-oriented Electrical Steel Sheet for Low Iron Loss Transformer Use "JGSD"

Reducing iron loss (core loss) in grain-oriented electrical steel sheet is a never-ending problem, but has been required even more strongly in recent years from the viewpoint of energy saving.

The reduction of iron loss in grain-oriented electrical sheet has been pursued mainly in two ways; by reducing hysteresis loss by increasing the degree of the grain alignment in the {110}<001> orientation (high magnetic flux density), and eddy current loss by adopting a higher Si content or reducing sheet thickness. Moreover, JFE Steel has developed an industrial technology for magnetic domain refinement which reduces eddy current loss by artificially refining the 180° domain width, enabling a large reduction in iron loss.[9]

JFE Steel has developed a heat-resistant type, magnetic domain refining technology applied to both stacked core transformers and wound-core transformers, even though the latter requires stress relief annealing. The product sheet was commercialized as JGSD with thicknesses of 0.23 mm and 0.27 mm.[10] This technology utilizes a process in which linear grooves are formed by local electrolytic etching of final cold rolled steel sheets, and the magnetic domains are refined by the magnetostatic energy of free magnetic poles generated by this groove shape. As one of the advantages of this process, iron loss can be reduced with no large deterioration in magnetostriction, because the domains can be refined without introducing strain into the steel sheet.

As can be understood from **Photo 4**, magnetic domains are significantly refined by grooves. From **Fig. 5**, it is obvious that there is a marked improvement in iron loss $W_{17/50}$ (iron loss at 1.7 T, 50 Hz) by introducing grooves. Since the effect of domain refinement is more pronounced in higher B_8 materials, as shown in the figure, high magnetic flux density material, JGS, is the main material made using this technology.

The magnetic properties of wound-core transformers using the heat-resistant type, domain-refined material 23JGSD085 and a comparison material, 23JGS090, are shown in **Table 2**. It is understood that the properties of the material as such are well reflected in the properties of the cores, because the building factor (BF) is very similar in the two materials, at basically 1.0, and almost the same results are also obtained for noise values.

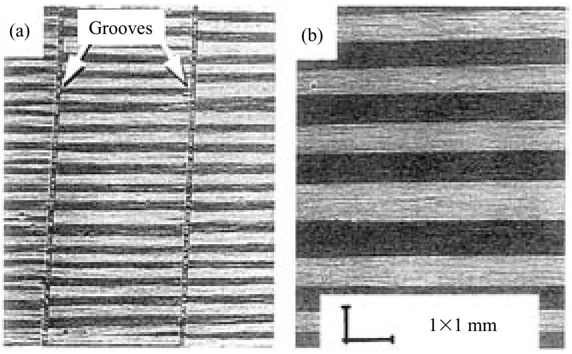

Photo 4 Magnetic domain structures of (a) grooved and (b) plain materials observed by type-II Lorentz SEM method

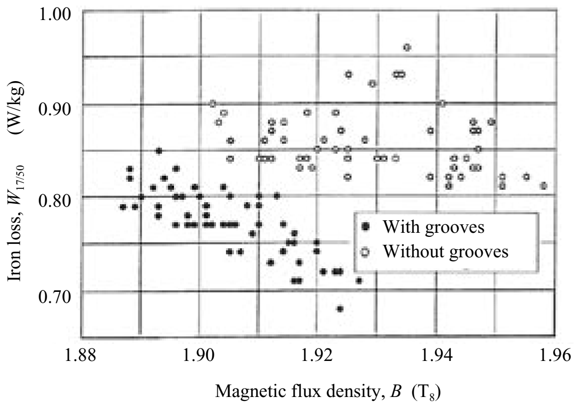

Fig. 5 Change in iron loss of grain-oriented electrical steel (Sheet thickness : 0.23 mm)

Table 2 Magnetic properties of wound-core transformer

Grade	Sheet properties		Transformer properties		
	B_8 (T)	$W_{17/50}$ (W /kg)	$W_{17/50}$ (W /kg)	BF for $W_{17/50}$	Noise level (dBA)
23JGSD085	1.90	0.78	0.79	1.01	43
23JGS090	1.93	0.89	0.91	1.02	42

BF: (Building factor) = (Tansformer iron loss) / (Sheet iron loss)

3.3 Grain-oriented Electrical Steel Sheet with Excellent Magnetic Shielding Property "JGMS"

As a distinctive feature of electrical steel sheets even including non-oriented material, these products are manufactured by controlling the texture of the easy magnetization axis parallel in the rolling plane. Grain-oriented electrical steel sheets, above all, can be achieved with highly aligned grains in the {110}<001> orientation, so-called Goss orientation, by secondary recrystallization. The properties required for magnetic shielding include (1) high magnetic flux density, (2) high permeability, and (3) low coercive force. They are the basic properties for effectively introducing and enclosing magnetic flux in a small volume, and are also common requirements in iron core materials for transformers and motors, which are typical applications of electrical steel sheets.

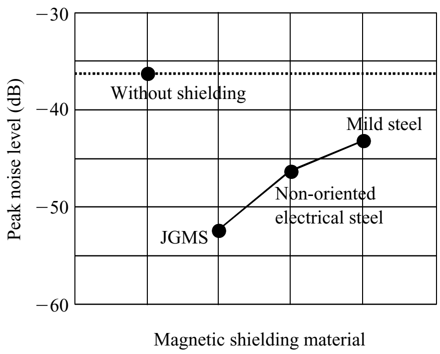

Fig. 6 Variation of peak noise level from a motor before and after shielding with different materials

Here, we will discuss the magnetic shielding material JGMS, which uses a grain-oriented electrical steel sheet as the base material, referring to a simple experiment as an example. The object of the experiment is to study the motor noise caused by the magnetic field generated by a small motor in a commercially available cassette tape recorder. Using the magnetic head of a tape recorder itself as a probe, the signals taken from a headphone jack through an amplifier were subjected to frequency analysis in a spectrum analyzer. To compare the shielding effects of different materials, the noise spectrum was measured in a condition in which a motor body was wrapped twice with JGMS (thickness: 0.23 mm), and when the motor was wrapped twice with a non-oriented electrical steel sheet (thickness: 0.20 mm) or with a mild steel sheet (thickness: 0.20 mm). In all cases, measurement was made at a position 10 mm apart from the motor and the maximum peak strength was obtained at 120 Hz. **Figure 6** shows the noise level, with the measured voltage of peak noise expressed in decibels. In comparison to the measurements without shielding material, noise improved by 7 dB with mild steel, 10 dB with the non-oriented electrical steel sheet, and 16 dB with JGMS, demonstrating a remarkable magnetic shielding effect.

With the increase in the use of magnetic recorders and the equipment which handles weak signals, now the importance of EMC and necessity of electromagnetic shielding have increased substantially. MRI, which is a widely used type of medical equipment, requires an exclusive-use shield room, and construction methods which take advantage of material properties are also being widely researched. Although shielding materials are selected based on the level of shielding provided with a magnetic field in question, JGMS is a promising shielding material in terms of both economy and stable properties.

3.4 Non-oriented Electrical Steel Sheet with High Formability for High Efficiency Motors "JNE"

The need for higher efficiency in motors which is symbolized by the introduction of the top-runner system for home appliances has also given impetus worldwide to improvement in the quality of the non-oriented electrical steel sheets for motor cores. In particular, the adoption of inverter type motors utilizing power electronics is an increasingly important trend for high efficiency motors. In this case, since the speed region at which the motor shows its highest efficiency in use corresponds to a relatively high frequency region, it is concluded that iron loss in the high frequency region is a more appropriate index of motor efficiency than the conventional evaluation of iron loss at commercial frequencies. The following introduces a new non-oriented electrical steel sheet, JNE, in which hardness (formability) is improved simultaneously with high frequency iron loss.

The magnetic properties of non-oriented electrical steel sheets are improved by reducing eddy current loss, which is achieved by adding elements such as Si, Al and Mn (electrical resistivity elements) that impart high electrical resistance. On the other hand, since motor cores are mass produced by punching, high importance is attached not only to magnetic properties, but also to die wear during processing. From the empirical knowledge, it is known that die wear becomes desperate when the Vickers hardness (HV1) of the material exceeds 220 points. Besides, with changing material property requirements, improvement of magnetic properties only by adding resistivity elements has reached its limits.

JNE, based on the conventional non-oriented electrical sheet JN, achieves low hardness combined with low iron loss by optimizing the composition of added resistivity elements and by reducing impurity elements such as S, O, N, etc. in the material, while performing control to suppress the (111) texture, detrimental to magnetic properties, and increase the (100) and (110) textures in the manufacturing process. **Figure 7** shows the relationship between iron loss $W_{10/400}$ in the high frequency region of 1.0 T-400 Hz and magnetic flux density B_{50}, and the hardness HV1 of the conventional non-oriented electrical steel sheet JN and the newly developed JNE (thickness: 0.35 mm). As a distinctive magnetic property of the JNE series, in a comparison at the same iron loss, the JNE series shows magnetic flux density B_{50} values 0.002–0.003 T higher than those of the JN series. Using materials with higher magnetic flux density is advantageous in order to downsize motors due to employing a design of higher magnetic flux density. The material with lower iron loss can be also used with JNE than with JN comparing at the same level of die wear because of

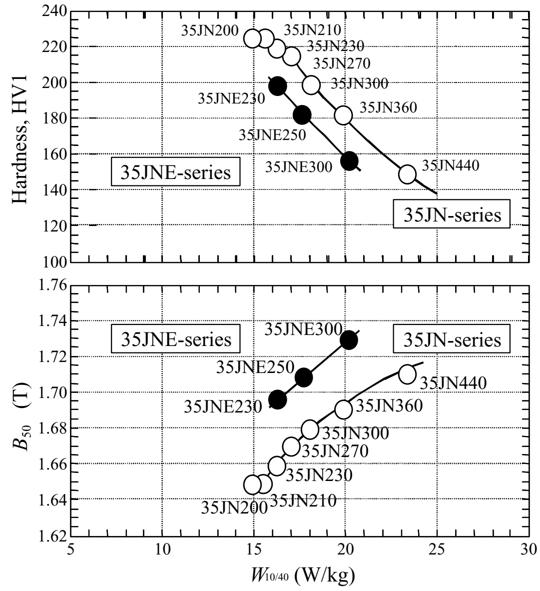

Fig. 7 Magnetic and mechanical properties of JNE and JN series

the distinctive mechanical property of low hardness of JNE series. Consequently, further improvement of motor efficiency can be expected.

With continuing progress in downsizing and higher outputs in motors, a trend toward higher frequencies in motor drives is expected in the future. Therefore, considering the fact that eddy current loss in non-oriented electrical steel sheet is proportional to the square of the sheet thickness and excitation frequency, the reduction of sheet thickness should be studied as an effective means of reducing eddy current loss. **Figure 8** shows the value of iron loss $W_{10/400}$ and $W_{10/1\,000}$ at 1.0 T-400 Hz and 1 000 Hz when the sheet thickness was changed by laboratory treatment using JNE base material. Since iron loss decreases in a substantially linear manner with reducing the sheet thickness, an improvement of approximately 30% in $W_{10/400}$ and 40% in $W_{10/1\,000}$ can be expected at the thickness of 0.20 mm in comparison with

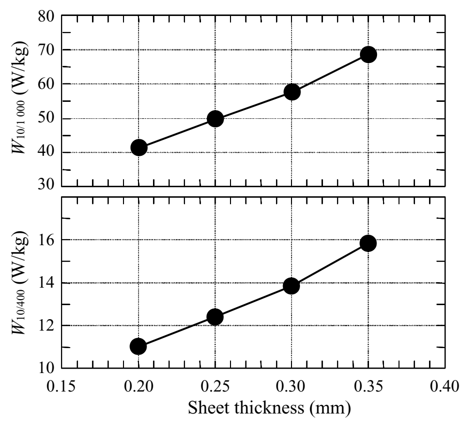

Fig. 8 Influence of sheet thickness on iron loss at high frequency

0.35 mm. In other words, as the excitation frequency increases, the ratio of eddy current loss to total iron loss increases, so the improvement of iron loss made by thickness reduction increases. Problem in that, in addition to the increased cost on the producer side, productivity is also reduced in manufacturing motor cores due to the increase in number of sheets in a core. Looking to the future, however, this technology is considered to have the potential for wide use.

JFE Steel has created a system for timely development of technologies which further improve iron loss in JNE series of non-oriented electrical steel sheets, including thickness reduction technologies.

3.5 Adhesive Type Organic Coating for Non-oriented Electrical Steel Sheets "B Coating"

After non-oriented electrical steel sheets are punched to the specified shape and stacked, various methods are employed to fix the material for use as iron cores in motors and small transformers. Core fixing methods include welding, interlocking, bolting, and so on. However, all of these methods cause anomalous distribution of the magnetic flux at the joining parts, which deteriorates motor performance. In contrast, with adhesive type B coating material, the surface is coated in advance with a heat-fusing type organic adhesive, making it possible to fix the entire sheet without any deterioration of performance by adhesion through a pressing, and heating process after punching.

(1) Recommended Adhesion Conditions for B Coating

Adhesion temperature and time: After heating to 200–250°C, hold for 10 s or longer; pressing force: 1 N/mm^2 or higher; room temperature adhesive strength (single lap shearing force): 10 N/mm^2 or higher.

(2) Advantages of B Coating Material

(a) Motor performance

As an example, the measured efficiency of an AC induction motor assembled using 50JN700∗B is shown in **Fig. 9**. In the 30–90 Hz inverter frequency range, satisfactory results were obtained with adhesive type core assembly, which showed a motor efficiency 0.23–0.58% higher than with the conventional bolting method.

(b) Noise

Similarly, the noise characteristics of the model motors is shown in **Fig. 10**. In order to compare noise due to excitation, a rotor with large mechanical noise was fixed and noise was measured in a non-rotating condition. With the adhesive method using B coating, noise was 2–5 dB less than with a motor using the bolting method with the A1 coating (general-purpose coating). It is considered that motor loss, noise, and other performance characteristics are improved with the adhesive method in comparison to the bolting method because non-uniform stresses acting on the motor core are reduced and the rigidity of the core is increased.

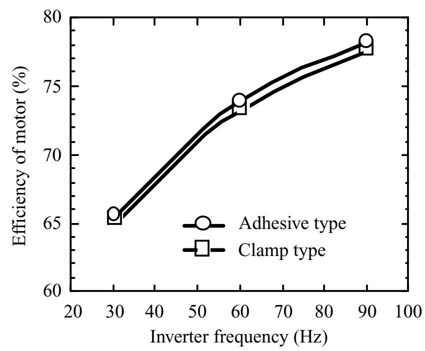

Fig. 9 Effect of core assembly method on efficiency of model motor using 50JN700∗B as core material

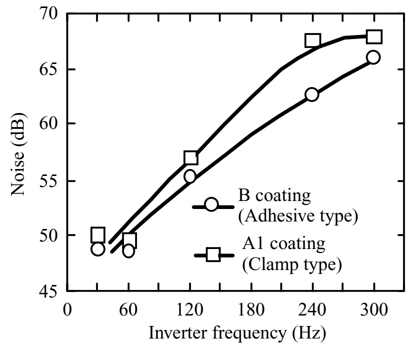

Fig. 10 Comparison of B and A1 coatings in noise emitted from model motor

(c) Punching properties

Since B coating is an organic one, punching properties are extremely good.

4. Low Loss MnZn Ferrite for Power Supply Use

Soft ferrite has substantially higher resistivity than metallic soft magnetic material and displays excellent soft magnetic properties in the frequency range from several kHz to several hundred MHz. Therefore, it is widely used in cores for high frequency transformers, choke coils, noise filters, and similar devices. Worldwide demand for soft ferrite is rising in response to the popularization of personal computers, cell phones and other personal electronic equipment. In these fields, the requirements placed on ferrite cores include higher performance, meaning higher frequencies, lower loss, higher permeability and higher magnetic flux density in comparison to the conventional materials, as well as reduced size and thinner profiles. Moreover, competitive pricing also becomes extremely intense due to the successive entry of Chinese makers in to these fields.

JFE Steel, as part of its new business development strategy, entered the MnZn soft ferrite business by establishing Kawatetsu Magnex (former name, now called JFE Ferrite) in Oct. 1990. In cooperation with JFE Ferrite, JFE Steel has been developing materials with outstanding properties, including loss and permeability, taking advantage of JFE Steel Group's strength as the only maker in Japan with an integrated production system from iron oxide material to ferrite core products, and also developed a roller hearth kiln which enables precise control of the sintering atmosphere, realizing both high performance and high productivity.

The materials developed to date are shown in **Fig. 11**. Their features are discussed in the following. MB4 is a low loss material for switching power supplies, with core loss of 280 kW/m^3, approximately 20% lower than that of MB3, the general-purpose material for power supplies. The reduction of core loss meets the social need for energy saving. MBT2 improves temperature dependence of core loss, which is a disadvantage of the ordinary power supply materials, showing low loss from room temperature to 100°C (**Fig. 12**). This material is expected to widely used for applications characterized by large changes in the temperature environment, such as automobiles. MB1H has an excellent balance of a saturation flux density and core loss, 460 mT (100°C) and 400 kW/m^3 (100 kHz, 200 mT, 100°C) respectively, and is used in general small-scale power supply applications with capacities of less than 50 W. MC2 has a world's No. 1 product with core loss of 65 kW/m^3 (500 kHz, 50 mT, 100°C), and is used in special power supply applications which require small size and thin profile. MBF4 has the unparalleled property of core loss $\leqq$ 300 kW/m^3 over a wide frequency range, namely, in the conditions of both "100 kHz, 200 mT" and "300 kHz, 100 mT", and is expected to be used in automotive applications where higher frequencies are progressively adopted.

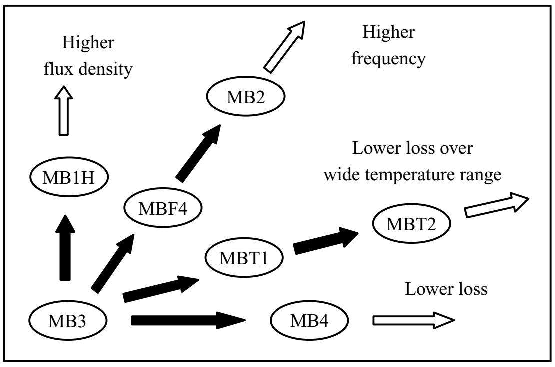

Fig. 11 Schematic diagram of development of the materials for switching power supplies

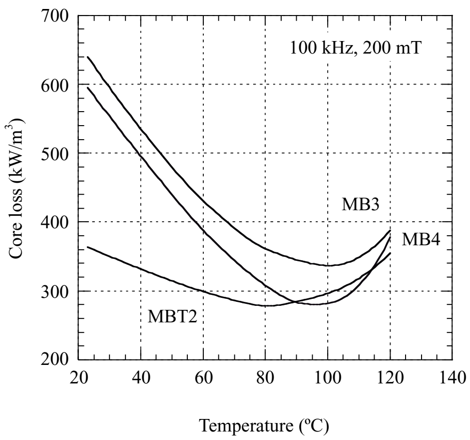

Fig. 12 Temperature dependence of core loss at 100 kHz and 200 mT of low loss materials, MB3, MB4 and MBT2

This section has briefly described the state of development of low loss materials for power supplies by JFE Steel and JFE Ferrite over the period of more than 12 years since JFE Steel Group entered the soft ferrite business. In the future, JFE Steel Group will continue to develop the materials capable of meeting the requirements of lower loss, higher permeability and higher frequency and supply these products through the production and marketing divisions of JFE Ferrite and JFE Ferrite Thailand.

5. Silver Dispersed Stainless Steel with Antibacterial Property

Since the mass infection caused by the *Pathogenic Coli*: O-157 in 1996, consumers awareness of safety and hygiene in tableware has risen rapidly. In response to this social condition, antibacterial products have been developed in a variety of fields, including sanitation fixtures, plastics, clothing and others. Cu-bearing stainless steel was developed as an antibacterial stainless steel, but had the major disadvantage of reduced corrosion resistance. JFE Steel therefore turned its attention to silver (Ag), which has a high antibacterial property, and carried out research aiming at imparting antibacterial performance to stainless steel without reducing its inherent properties, particularly, corrosion resistance. As a result, the company succeeded in realizing both stable antibacterial property and corrosion resistance equal to that of the conventional stainless steel by uniformly dispersing fine particles of Ag in the steel. JFE Steel has developed three grades of Ag-bearing antibacterial stainless steel, an austenitic type of JFE304-AB (18%Cr-8%Ni-0.04%Ag) and ferritic types of JFE430LN-AB (17%Cr-0.4%Nb-0.04%Ag) and JFE430-AB (16%Cr-0.04%Ag).

As shown in **Fig. 13**, the Ag-bearing steels exhibited antibacterial effects not only in *Ecsherichia Coli* and *Staphylococus Aureus*, but also in O-157, MRSA, which is a bacterium that causes infection in hospitals, and the *Salmonella* bacterium. In terms of corrosion resistance, these materials show the same properties as the Ag-free stainless steel. At present, the developed steels are

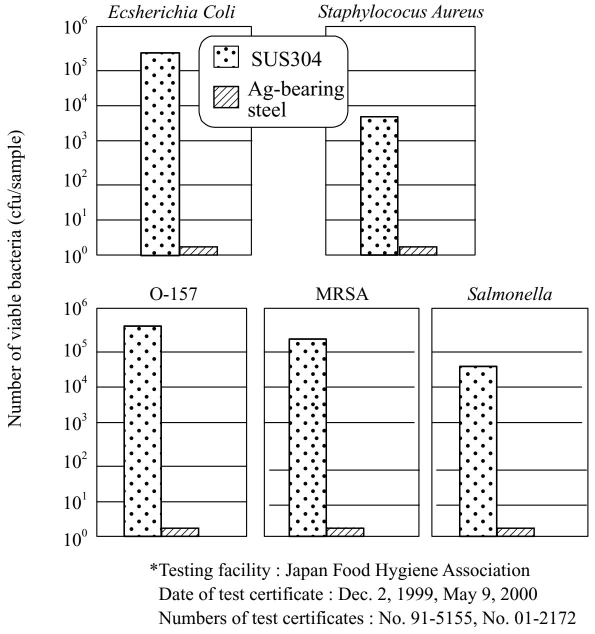

Fig. 13 Results of antibacterial test* of 0.042 mass% Ag-bearing steel

actively used in washing vessels, kitchenwares, tablewares, and hospital interior materials, and a progressive adoption in other fields where sanitation control is necessary is expected in the future.

6. Environment-friendly Low Carbon Lead-free Free Cutting Steel Bar and Wire Rod Products for Printer Shafts

Since lead-bearing free cutting steel has high machinability, it is used in large quantities for shafts of electrical products such as printers. However, a practical Pb-free steel had been desired due to the concern about negative effects on the environment. JFE Steel developed two types of Pb-free free cutting steel, a microstructure-controlled steel for carbide tools which is particularly suitable for light machining conditions and a sulfide shape-controlled steel which can be used in cemented carbide and high speed steel tools.

6.1 Microstructure-controlled Pb-free Free Cutting Steel "NFK1"

6.1.1 Features

Sulfur (S) was added to free cutting steel to persuade the formation of sulfide type inclusions such as MnS in the steel, with an aim of improving machinability by the stress concentration effect. As the features of this steel, NFK1, sulfide type inclusions are the same as in the conventional S-bearing free cutting steel, but machinability is improved by controlling the microstructure of the steel mother material using a revolutionary new method. As the mother material microstructure, the conventional ferrite-pearlite structure is changed to that mainly consisting of bainite by fine adjustment of the chemical composition and control of the manufacturing process.

Table 3 Chemical composition

(mass%)

Steel	C	Si	Mn	P	S	Nb	Pb
NFK1	0. 03	Trace	1. 10	0. 070	0. 34	Added	Trace
12L14	0. 07	Trace	1. 05	0. 070	0. 34	Trace	0. 24

Table 4 Mechanical properties

Steel	YS (MPa)	TS (MPa)	El (%)	RA (%)
NFK1	303	396	33	69
12L14	289	409	30	43

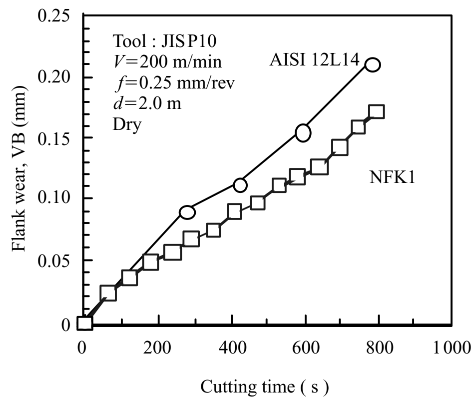

Fig. 14 Comparison of flank wear between NFK1 and AISI 12L14

6.1.2 Examples of chemical composition and mechanical properties

Table 3 shows an example of chemical composition. **Table 4** shows mechanical properties, which are substantially equivalent to those of AISI 12L14.

6.1.3 Machinability

This steel is suitable for the application of carbide cutting tools, and shows high machinability (tool life, surface roughness, chip disposability) when used with tools of this type. **Figure 14** shows an example of tool life in turning with a carbide tool. In comparison to AISI 12L14, the progress of tool wear is gradual and tool life is satisfactory.

6.2 Sulfide Shape-controlled Pb-free Free Cutting Steel "CCC12C14"

6.2.1 Features

It has been known for a long time that the machinability of S-bearing free cutting steels improves as the size of the sulfide inclusion increases or the inclusion becomes a spindle (fusiform) shape. As features of this steel, machinability is improved by forming large sulfide inclusions, which became possible for the first time by increasing the amount of S addition while also adding Cr. This steel, named CCC12C14 (clean cut chrome), was the result of joint development with Prof. Kiyohito Ishida of Tohoku Univ. and Senior Researcher Katsunari Oikawa of the Tohoku Center of the National Institute of Advanced Industrial Science and Technology. It shows satisfactory machinability in cutting with either carbide or high speed steel tool, and can be applied to all parts where the AISI 12L14 steel is currently used. Since carburizing characteristics of this steel are also equal to those of AISI 12L14, it can also be applied to carburized parts.

6.2.2 Examples of chemical composition and mechanical properties

Table 5 shows an example of chemical composition. **Table 6** shows the mechanical properties, which are substantially equivalent to those of AISI 12L14.

6.2.3 Machinability

Under the conditions shown below, machinability is equal or superior to that of AISI 12L14.

(1) Turning with carbide, coated carbide, or cermet tool (tool life)
(2) Turning with high speed steel tool (tool life)
(3) Drilling with high speed steel tool (tool life)
(4) Chip disposability

Table 5 Chemical composition

(mass%)

Steel	C	Si	Mn	P	S	Cr	Pb
CCC12C14	0.05	Trace	0.58	0.076	0.385	1.00	Trace
AISI 12L14	0.07	Trace	1.05	0.070	0.340	0.08	0.24

Table 6 Mechanical properties

Steel	YS(MPa)	TS(MPa)	El(%)	RA(%)
CCC12C14	298	401	36	57
AISI 12L14	289	409	30	43

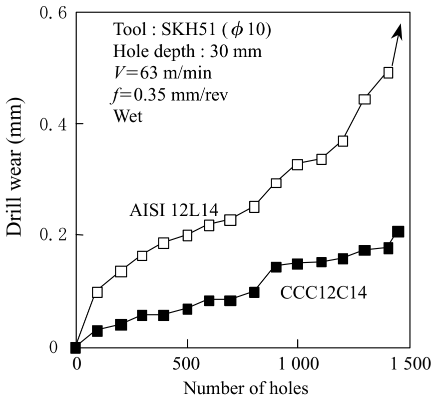

Fig. 15 Comparison of drill machinability between CCC12C14 and 12L14

Figure 15 shows an example of tool life in drilling with a high speed steel tool. In comparison to AISI 12L14, the progress of tool wear is gradual and to tool life is satisfactory.

7. Alloyed Steel Powder for Sinter Hardening "KIP 21SX"

Conventionally, a heat treatment such as carburizing quenching and tempering was necessary in manufacturing high strength, high hardness sintered parts, but its process increased costs. JFE Steel therefore developed an alloyed steel power, KIP® 21SX, which can obtain high strength and high hardness in sintered parts without heat treatment after sintering.

KIP 21SX is a hybrid type alloyed steel powder in which hardenability is improved while maintaining proper compressibility by adhering Ni powder, Cu powder and graphite powder to the prealloyed steel powder with a 2 mass%Ni-1 mass%Mo composition (hereinafter called base steel powder) using binder. As a distinctive feature, the properties of the sintered compacts can be modified by changing the amounts of the adhered elements in response to property requirements.

The following describes the properties of sintered compacts of standard composition KIP 21SX, in which 2 mass% Ni powder, 1.5 mass% Cu powder and 0.6 mass% graphite powder are adhered to the base steel powder.

Figure 16 shows the relationship between the sintered density and tensile strength of KIP 21SX in comparison to KIP Sigmaloy 415 S (4Ni-1.5Cu-0.5Mo partially alloyed steel powder), which is used in a wide range of sintered parts. When prepared by sieving the base steel powder to under 180 μm, the 21SX ($-180\ \mu$m) shows higher tensile strength than Sigmaloy 415 S at the same density. Furthermore, higher tensile strength can be obtained with 21SX ($-150\ \mu$m) when the base steel powder is sieved to under 150 μm.

The relationship between sintered density and hardness is shown in **Fig. 17**. Independent of the particle size of the base steel powder, the hardness of 21SX was higher than that of Sigmalloy 415 S, and was on the same level (30–35 HRC) as the heat treated materials.

The microstructures of sintered compacts are shown in **Photo 5**. The microstructure of the sintered compact of 21SX consists of light gray colored martensite, white colored austenite, and dark gray colored bainite. In comparison to that of the Sigmaloy 415 S sintered compact, the percentage of martensite is high. Moreover, the percentage of martensite is higher in 21SX ($-150\ \mu$m) than in 21SX ($-180\ \mu$m). The higher martensite ratios in these two cases are considered to be the main factor for high strength and high hardness.

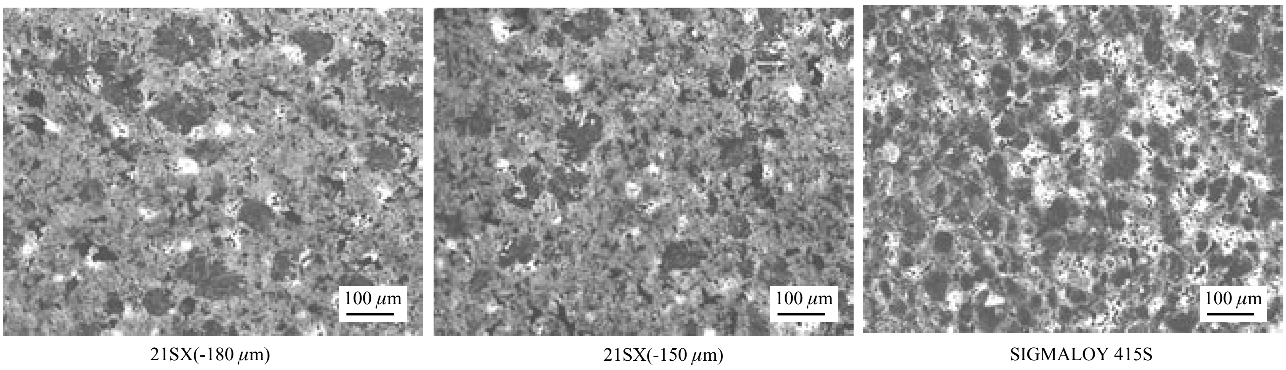

Photo 5 Microstructures of sintered compacts made of KIP 21SX and SIGMALOY 415S

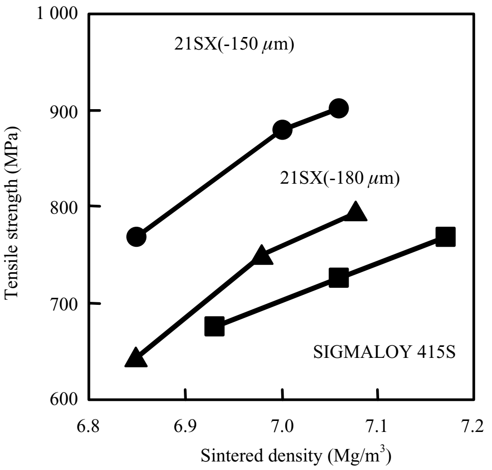

Fig. 16 Relations between sintered density and tensile strength of sintered compacts made of KIP 21SX and SIGMALOY 415S

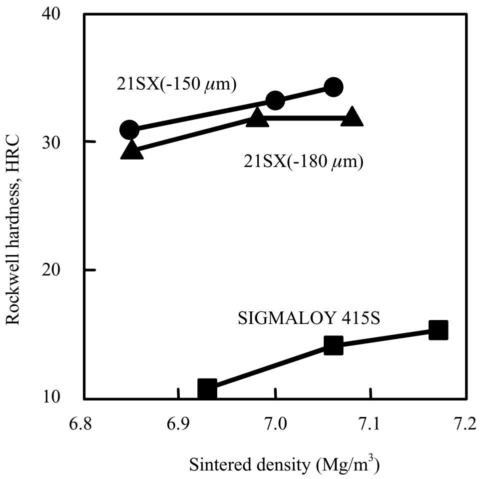

Fig. 17 Relations between sintered density and hardness of sintered compacts made of KIP 21SX and SIGMALOY 415S

In the future, KIP 21SX is expected to be used in manufacturing home electric appliance parts, power tool parts, automotive parts and others which require a combination of low cost and high strength/high hardness properties.

8. Negative Electrode Material of Mesophase Graphite for Li^+ Secondary Batteries

The mesocarbon microbead is a material which was developed as part of JFE Steel's strategy of creating high value added products from coal-tar pitch. When coal-tar pitch is heat treated, a condensation polymerization reaction occurs in the liquid phase, forming large polycyclic aromatics. Optically anisotropic small spheres (mesophase spheres) are then formed, as shown in **Photo 6**, by stacking the aromatics. These micro spheres are separated using an aromatic solvent, producing mesocarbon microbeads having the diameter ranging from several microns to several tens of microns. The beads are converted to a graphite material by high temperature treatment.

JFE Steel carried out a research from the basic stage to that for industrial production, and became the first maker in the world to succeed in industrial-scale production of mesocarbon microbeads (trade name, KMFC: Kawasaki mesocarbon fine carbon) using its own proprietary technology. The main applications of this product are high density/high strength graphite materials and negative electrode materials for lithium ion secondary batteries. To meet demand, JFE Chemical, in the JFE Steel Group, owns and operates a 840 t/y plant at its East Japan Works and a 1 200 t/y plant at its West Japan Works.

The Li^+ secondary batteries have become an essential element device in mobile electronic products such as personal computers and cell phones. These batteries are based on the principle that lithium ions flow back and forth between a positive and a negative electrodes, and normally use a graphite material as the negative electrode. Since a graphite structure is also achieved with mesocarbon microbeads by high temperature treatment (graphitization), they can be used as a negative electrode material. Mesophase graphite shows a flat electrical potential characteristic of graphite materials, as can be seen in the discharge curve in **Fig. 18** (to Li metal as a reference electrode). JFE Steel carried out research

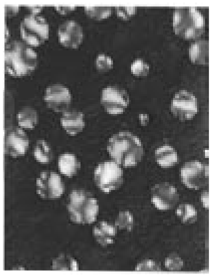

Photo 6 Polarized micrograph of mesophase spheres formed in coal-tar pitch

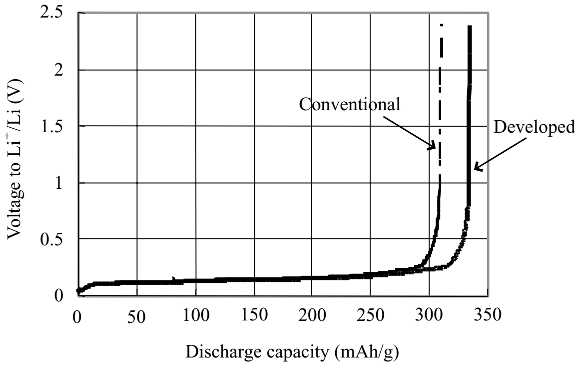

Fig. 18 Discharge capacity of developed and conventional KMFC graphite powders

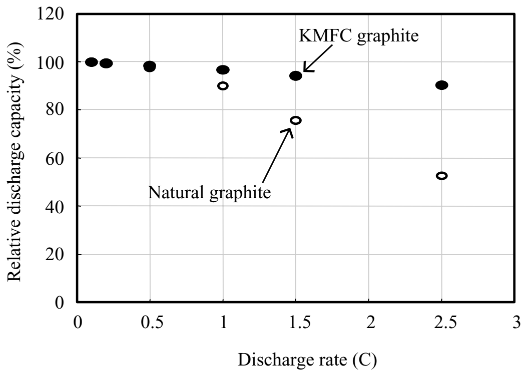

Fig. 19 Comparison in relative discharge capacity of developed KMFC graphite powders and natural graphite powders

and development to realize a high capacity product and completed the development of mesophase graphite with a capacity of 340 mAh/g, or approximately 20 mAh/g higher than the conventional type.

Although improved crystallinity is necessary in order to achieve high capacity, graphite materials generally tend to assume a flat shape as their crystallinity increases. If the material is flat, however, diffusion of lithium ions in the electrolyte is impeded because the material tends to cover the electrode, making it impossible to meet rapid charge/discharge requirements. **Figure 19** shows a comparison in the discharging property between the developed KMFC and the conventional flat-shaped natural graphite powders at high discharge rates. Because KMFC has a spherical shape, it has a high capacity maintenance ratio (relative discharge capacity) even at high discharge rates.

As summarized above, KMFC is a material with an excellent total combination of properties for negative electrodes. JFE Steel is continuing research and development to achieve higher capacities in order to supply even more outstanding negative electrode materials to its customers.

9. Conclusions

Iron and steel products are used in an astonishingly wide range of applications in home electric appliances and power industry. The typical products described above are used in refrigerators, washing machines and other home appliances, information technology equipment beginning with personal computers and cells phones, and energy-efficient motors and heavy equipment in the power industry, in a range of parts which includes outer and inner panels, for example, drums, roll shafts, motor cases, motor and transformer cores, gears and battery electrodes. While these products reduce environmental loads and improve energy efficiency, JFE Steel is also confident to contribute towards our society by broadening the application and research on use technologies of our steel products that maximize the advantages of steel as easily recycled product.

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