JFE TECHNICAL REPORT
No. 2 (Mar. 2004)

Materials and Technologies for Automotive Use†

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Abstract:

JFE Steel supplies a wide range of advanced products and technologies to automotive industry. This report first introduces new high strength steel products which contribute to reduction of automobile weight and improvement of crashworthiness, coated steel products for extended automobile life, and evaluation and application technologies of steel products. In addition, several other products are also introduced, such as stainless steel products for exhaust system, electrical steel sheets with outstanding high frequency properties, ERW tubes for hydroforming, bar products for bearings and power train parts iron powder technology for high density sintered parts and lightweight composites for interior parts.

1. Introduction

The functions required in automobiles in recent years have become increasingly diverse. In addition to the essential functions of transportation and comfort, high fuel efficiency and emission control from the viewpoint of global environmental protection and safety and durability as people-friendly features have nowadays become indispensable.

And realizing of automobile weight reduction, improvement of crashworthiness and extended life of body parts are considered as the main approaches to achieving those goals. From the strategic viewpoint, shortening the development period is also an important issue.

To respond to those needs in the automotive industry, JFE Steel has been paying great efforts to not only developing of suitable steel products for each automotive part but in the strengthening of its application technology as well. Thanks to these efforts, the company now has become possible to provide EVI (early vendor involvement) activities to customers for proposing of the optimum steel products for each automobile parts together with the appropriate manufacturing methods.

The following introduces JFE Steel's automotive steel products line and EVI technologies, which are presently used in the world-leading automobile manufacturing.

2. Steel Sheets

2.1 High Strength Steel Sheets

2.1.1 New precipitation-hardened high strength hot rolled steel sheet "NANO-Hiten"

Since the hot rolled steel sheets used in the underbody parts are usually press-formed by complexed deformation modes which include stretch forming, burring and other types of stretch flange forming, the sheets must have the sufficient balance of elongation and hole-expansion ratio. To realize these properties, JFE Steel began development of a 780 MPa class high strength hot

† Originally published in *JFE GIHO* No. 2 (Nov. 2003), p. 1–16


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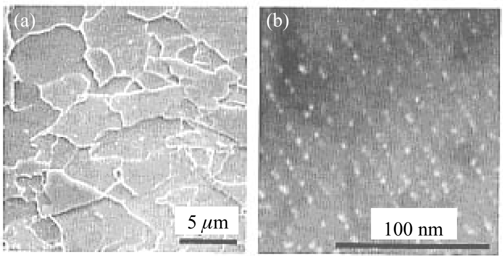

Photo 1 Microstructure (a) and precipitates (b) of NANO Hiten

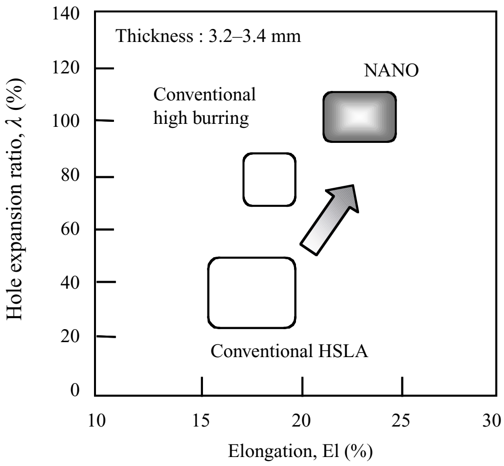

Fig. 1 Comparison of El-λ balance of 780 MPa grade hot rolled steels

rolled sheet on the basis of a new metallurgical concept, and succeeded in developing and commercializing a unique hot rolled product called "NANO Hiten (NANO: new application of nano obstacles for dislocation movement)" [1].

The NANO Hiten has the following three features:

(1) Single phase ferrite structure with high formability
(2) Strengthening by precipitates refined to the size of several nanometers
(3) Extremely high thermal stability of precipitates

Although the diameter of the precipitates (NbC, TiC, etc.) observed in conventional precipitation-hardened steels have been several 10s nanometers, this is refined down to several nanometers in the NANO Hiten, and an innovative technology is used to improve thermal stability. To achieve such precipitates, X-Y-C ternary carbide system was studied by varying the combinations of X and Y, and it was found that very fine precipitates could be obtained in a system where the proper amounts of Ti and Mo were added to a C-Mn steel. Furthermore, these precipitates show extremely high thermal stability[2].

Typical examples of the microstructure of the NANO Hiten and the precipitates in the foil are shown in **Photo 1**. The microstructure is a single ferrite phase and has a large number of ultra-fine precipitates of about 3 nm lie in rows. The NANO Hiten has commercially achieved extremely fine precipitates with the size of several nanometers for the first time in the world.

Figure 1 shows the relationship between elongation and hole expansion ratio in NANO Hiten, in comparison with the properties of a conventional precipitation-strengthened type and a high burring type high strength hot rolled steel sheets. The NANO Hiten has more excellent balance between elongation and hole expansion ratio than those of the conventional steels. This is attributed to the ferrite single phase microstructure and ultra-refinement of precipitates.

The NANO Hiten of 780 MPa grade has already being adopted in the automotive parts such as chassis and arm parts. Moreover, since Si is not added to NANO Hiten as a hardening element, it is suitable for high quality hot dipped galvanized sheets, and expected to extend to the field of the applications to 780 and 980 MPa galvannealed (GA) sheets.

2.1.2 New high strength hot rolled steel sheet for strain aging use "BHT"

JFE Steel succeeded in developing a new high strength hot rolled sheet for strain aging use which has a lower strength and higher formability when it is formed, and has a large increase in tensile strength through baking after painting, and also posses satisfactory anti-aging properties at room temperature[3,4]. **Figure 2** shows the stress-strain curves of the newly developed steel before and after strain aging. The great difference between the developed steel and the conventional BH steel is the increase in tensile strength shown by the new steel when baked. In the developed steel, such a high strain age hardening is idealized by using N, which has a higher solubility in the hot rolling temperature region than C. To ensure the solid solution of N in the sheet, the precipitation of AlN is suppressed by controlling cooling conditions after hot rolling. At the same time, to pre-

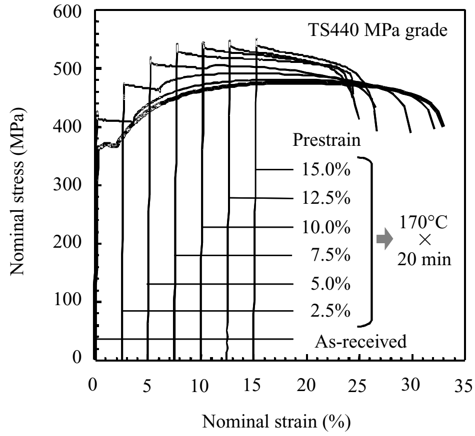

Fig. 2 Stress-strain relationship of newly developed steel after strain aging

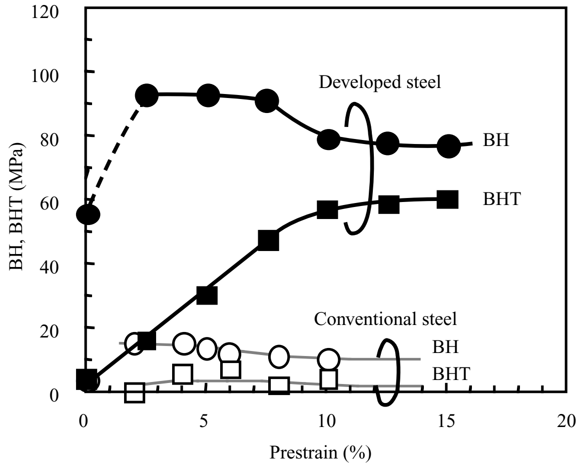

Fig. 3 Effect of prestrain on BH and BHT of newly developed steel after strain aging (t = 1.4 mm)

vent aging deterioration at room temperature due to diffusion of N, the area of grain boundaries is increased by performing quenching immediately after hot rolling to refine the grain size, causing the solute N to segregate to the stable position at the grain boundaries. This process makes the new steel successfully realize both high strain age hardening and satisfactory anti-aging property at room temperature.

Figure 3 shows the effect of prestrain on the increase in yield strength (BH) and that in tensile strength (BHT) due to baking at 170°C × 20 min after 0 to 15% prestrain by uniaxial tension, in comparison to the conventional steel. Important features of the developed steel in comparison to the conventional steels is that the BH shows a high value of approximately 100 MPa after 2% prestraining, while BHT shows a significant increase with the increase in prestrain up to 10%. At the prestrain of 10%, BHT reaches approximately 60 MPa, and shows little change with additional prestrain.

The study of the press formability of the developed sheet, including forming limit diagram (FLD) and dimensional accuracy, showed basically the same properties as the conventional sheet.

For the conventional steel sheets, absorbed energy during high speed deformation (i.e., crashworthiness) is improved by work hardening. However, in addition to work hardening, increased tensile strength due to strain age hardening also contributes to impact properties of the developed sheet. An FEM analysis showed that the contribution of strain age hardening in the developed sheet to the crashworthiness is equivalent to one-half gauge (0.1 mm) in the thickness of the hot rolled sheet or a tensile strength of 60–70 MPa. This means that the newly developed steel can contribute to the reduction of weight through reducing the sheet thickness, or to securing press formability of hard-to-form parts by using a lower strength material with the same thickness[5].

2.1.3 High strength galvannealed steel sheets

(1) SFG Hiten

In the automotive exposure panels, excellent deep drawing property and uniform good appearance are required. Recent years, high strength galvannealed steel sheets with a high drawability comparable to the mild steel has also been demanded for automobile outer panel, contributing to the weight reduction of body in white.

To meet these requirements, JFE Steel successfully developed a completely new type of fine-grained high strength steel sheet, SFG (super fine grain)[6], with high deep drawability and suitability for galvannealing, which effectively employs hardening both by grain refinement and by dispersion of precipitates. This was achieved by increasing the carbon content approximately 3 times higher than that in the conventional IF steels, and adding Nb exceeding the equivalent amount to encourage precipitate fine Nb carbides. Since the addition of solid-solution hardening elements such as Si, Mn, P, etc. can be reduced, the surface quality of SFG Hiten amply satisfies the requirements for use of GA in exposure panels. This product also demonstrates the possibility of achieving high r-values through the fine-grained structure, which was not possible with the conventional technology (**Fig. 4**).

As one important problem in press forming of panel parts using high strength steel sheets, it is essential to secure panel surface accuracy by improving the shape fixability. It is also necessary not only to improve forming technology, but also to improve the

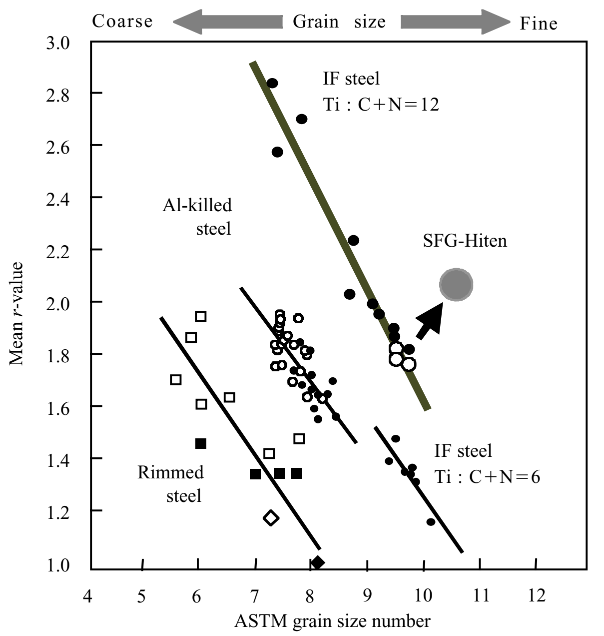

Fig. 4 Correlation between mean r-value and grain size in both SFG-Hiten and other conventional steels

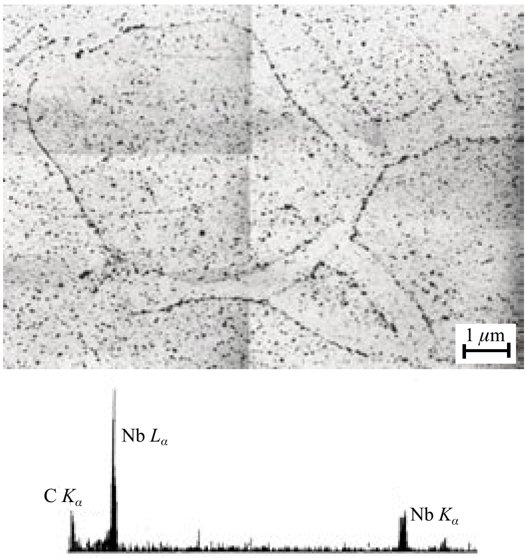

Photo 2 TEM image with replica and EDS spectra of precipitates observed in SFG-Hiten

uniform strain distribution by lowering yield ratio in steel, which leads to higher work-hardenability. In SFG Hiten, an NbC-depleted PFZ (precipitation free zone) is formed in the vicinity of the grain boundaries as shown in **Photo 2**, so that the material begins to yield at a lower strength around the grain boundary in the early stage of deformation during press forming. As a result, the newly developed sheet demonstrates a lower yield ratio and higher work hardening property than the conventional IF Hiten (HSSs). Consequently, the newly developed sheet has more resistance to wrinkles than the conventional steel, even under a low cushion force condition, and the surface distortion is expected to reduce in formed panels. Moreover, since this material also has a high *r*-value, it also resists cracking, even under a high cushion force condition, expanding the range of press formability to complex/complicated shapes which cannot be formed with the conventional steels.

(2) Low Carbon Equivalent Type Hiten

Generally, high strength is easily obtained in steel sheets by adding the necessary amounts of relatively inexpensive solid solution hardening elements such as C, Si, Mn, P, etc. However, a failure in weld metal occurs more easily with the increase in addition of elements which increase hardenability, such as C, Si, and Mn, and the elements which cause embrittlement in weld metal, such as P and S. Thus, from the viewpoint of spot weldability, the amount of these elements should be minimized. On the other hand, from the viewpoint of coatability, the excessive addition of Si and Mn tends to cause the enrichment of these elements on the sheet surface in the form of oxides, reducing product quality by deteriorating wettability of Zn, while P impedes the diffusion of Fe atoms at grain boundaries, reducing the alloying rate in galvannealing. Considering these various problems, the reduced addition of these elements is desirable.

JFE Steel therefore developed TS590–980 MPa in tensile strength (TS) GA steel sheets with excellent spot weldability by reducing the contents of elements which are disadvantageous for galvannealed sheet properties[7].

To secure high strength and simultaneously to improve coatability and spot weldability, the chemical composition was designed as shown in the following Eq. (1) so as to obtain a carbon equivalent P_{CM}[8] of 0.24% or less:

$$P_{CM}(\text{mass\%}) = C + Si/30 + Mn/20 + 2P + 4S \quad \cdots\cdots(1)$$

When manufacturing high strength GA sheets of the TS590–980 MPa grade, high strength is obtained by making maximum use of the respective strengthening mechanisms of precipitation hardening, strengthening by grain refinement, and structural strengthening, and utilizing an appropriate combination of limited kind and quanity of element, such as Ti, Nb, Mo and others which does not reduce spot weldability or coatability.

The low YR type GA sheets can achieve the value of El and λ equivalent to those of the conventional cold rolled steel sheets by optimizing the type and amount of addition of alloying elements such as C and Mn, which cause a significant increase in P_{CM}, and minimizing unavoidable impurities such as P and S. Moreover, even the high YR type GA sheets which employ mainly precipitation hardening and strengthening by grain refinement can secure satisfactory El value, equivalent to that obtained in the low YR type GA sheets. The developed steel is expected to be used as a sheet which ensures reliability of spot welds in auto body structural parts such as members and reinforcements.

Satisfactory weld strength can be secured with the developed GA sheets because it is possible to control failure mode of the spot welded joints to be a in the failure base metal by holding the P_{CM} value to a low level. In particular, as shown in **Fig. 5**, because the ductility ratio CTS/TSS of 0.5 or higher is secured in the spot welded joints (CTS/TSS: ratio of the cross tension strength to tensile shear strength), spot weld strength is superior to that of the conventional steels.

2.1.4 High formability ultra-high strength cold rolled steel sheets

By stabilizing quench strengthening with a low alloying design using the CAL water quench (WQ) process, JFE Steel successfully commercialized ultra-high strength cold rolled steel sheets (Ultra Hiten) with

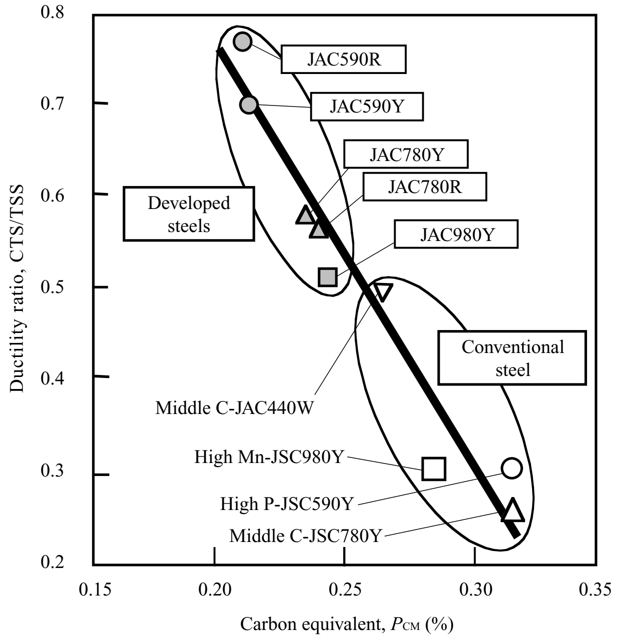

Fig. 5 Relationship between ductility ratio, CTS/TSS and carbon equivalent, P_{CM} at welding current of 7.5 kA

strengths from 980 MPa to 1 470 MPa. The Ultra Hiten is applied to safety reinforcement parts such as bumper reinforcements and door impact beams, and also to roll forming and pipe forming parts. The potential problem of hydrogen brittlement susceptibility in corrosive environments, which had been a concern in the Ultra Hiten with the strength level of above 1 180 MPa, was overcome by a design in the low carbon equivalent value and the control in the carbide morphology in the tempered martensite structure[9].

With heightened need for application of Ultra Hiten to parts with complex shapes, not only improvement in the ductility of the sheet, but also prevention of stretch flanging cracks originating at the blank edge has become important. JFE Steel, therefore, developed a sheet with excellent stretch-flangeability, similar to that of 590 MPa class high strength cold rolled steel sheets, using a high ductility dual phase (DP) steel as the base material by reducing the difference in strength between the ferrite and martensite phases[10]. To improve poor dimensional accuracy due to springback, which is a problem in press forming of high the strength steel sheets, the strength is stabilized in the coil longitudinal and transverse directions by stabilizing hardenability in the WQ process. It was also possible to reduce the strength deviation to the same level as in the 590 MPa grade high strength cold rolled steel sheets by controlling the chemical composition to a narrow range in the steelmaking process and by feed-forward control of factors causing strength fluctuations in the integrated manufacturing process.

As for the 980 MPa Ultra Hiten, a high ductility, low yield ratio DP steel sheet for the stretch forming and

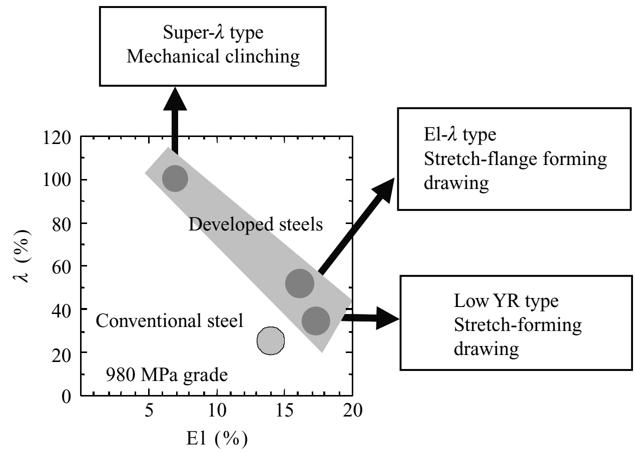

Fig. 6 Typical El-λ balance of newly developed 980 MPa grade ultra-high strength steels

an ultra-high λ type steel sheet for severe bend forming parts were developed[11]. In particular, the ultra-high λ type sheet achieves a hole expansion ratio superior to that of the 440 MPa grade steel sheets and is suitable for mechanical staking, which was in the past limited to the mild steel, aluminum and other low strength materials, opening the way to new fields of application such as weight reduction in automobile seat frames.

Figure 6 shows the development of new product types based on the El-λ balance of 980 MPa Ultra Hiten.

2.1.5 High carbon steel sheets with high formability

High carbon steel sheets are widely used in automobile drivetrain parts as the materials for machine structural usage. For example, in order to reduce costs, JFE Steel developed a method of heat the treating the high carbon cold rolled steel sheets after press forming as a substitute for the conventional casting and forging processes for the automotive parts such as ring gears and drive plates. However, in gear parts where the high dimensional accuracy is required, a leveling process for shape defects caused by anisotropy in the steel sheet is necessary. JFE Steel, therefore, developed a non-oriented high carbon cold rolled steel sheet with extremely small anisotropy in the sheet plane in addition to high formability and hardenability to enable the application of high carbon steel sheets to the hard-to-form and high dimensional accuracy parts of this type[12]. Earring after deep drawing of cup cylinder type is significantly reduced by refining cementite and controlling the recrystallization texture, making it possible to apply the material to rotating parts which must be free of eccentricity and display high circularity (**Fig. 7**).

In the unitary parts such as the clutch hub drum and planetary carrier of automatic transmissions, burring formability and a high deformation capacity (local ductility) during heavy forming are important in boss form-

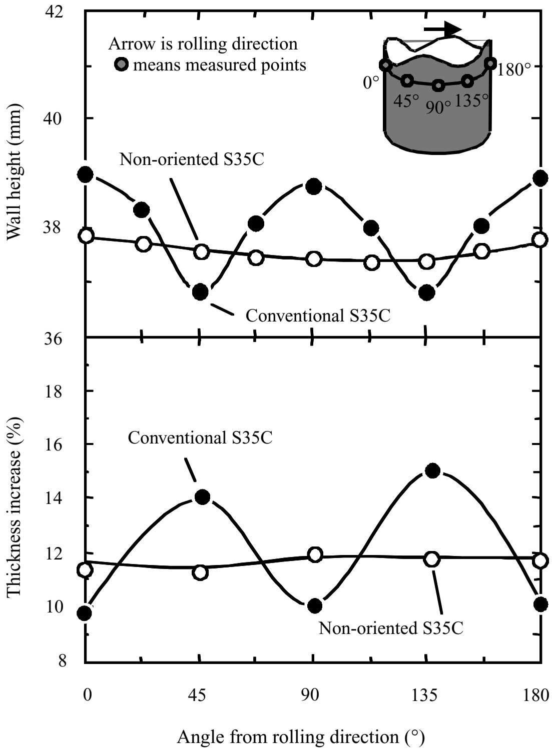

Fig. 7 Change in wall height and wall thickness after cup cylinder deep drawing

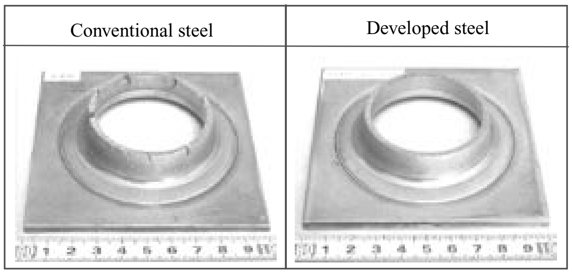

Photo 3 Hole expanded test piece (S35C)

ing and buildup processing. For these requirements, a high carbon hot rolled spheroidizing-annealed steel sheet with an excellent hole expansion property was developed using microstructure control through the application of high accuracy controlled cooling in the hot rolling process[13].

Photo 3 shows the appearance of test pieces after a hole expansion test which simulate boss forming for the conventional steel and the developed steel. The newly developed steel greatly increases the possibility of boss forming of high carbon steel sheets, which was difficult with the conventional steel, and expansion to applications such as unitary forming and local buildup is easy. Due to the uniform fine dispersion of cementite carbides, the developed steel shows excellent hardenability at a low temperature and short time heating by high frequency heating, as well as excellent punchability and uniformity in punched edges.

2.2 Coated Steel Sheets

2.2.1 Coated steel sheets with high lubrication for automotive use

With more complex press part shapes and accelerated adoption of high strength steel sheets in recent years, substantially improved press formability has been demanded to the steel sheets, drawing intense attention to surface lubrication technologies.

As part of this trend, because galvannealed sheets are now the mainstream material in rust-preventive (corrosion resistant) steel sheets for automobile use in Japan, development of a lubrication technology capable of imparting high lubricity to GA materials was strongly desired. JFE Steel has developed and commercialized two kinds of inorganic type high lubrication galvannealed steel sheets which respond to these needs, GA-N[14] and GA-K[15].

This section introduces the developed products and also describes an organic type solid lubrication technology.

(1) Development of Inorganic Type High Lubrication Galvannealed Steel Sheets

To improve the paint finishing property, double-layer galvannealed steel sheets (double-layer GA), in which Fe-Zn alloy electroplating or Fe-P electroplating is applied on the surface of GA[16], was developed. This material was eventually adopted to improve pressing properties, taking advantage of the good frictional properties of the Fe rich electroplated layer. Therefore, for the purpose of material cost reduction, JFE Steel carried out technical development of inorganic type high lubrication GA sheets based on the concept of achieving the same excellent lubrication property as double-layer GA, together with other required properties equal or superior to those of the conventional GA.

The GA-N is a material in which a Ni-Fe-O composite inorganic lubricant layer developed independently by JFE Steel is applied on the GA coating layer. The developed coating, as shown in **Fig. 8**, satisfies various property requirements at a high level by adopting a composite design of elements which are effective in achieving the property requirements of press formability, weldability and adhesive compatibility. As distinctive features, excellent press-formability and weldability are realized by using an extremely thin Ni type film with a thickness of approximately 50 nm (1/10 that of double-layer GA) in comparison with GA and double-layer GA. Press formability is also improved by using the Ni-Fe-O composite film with a high melting point, to improve anti-sticking property (prevention of metal-to-metal contact between

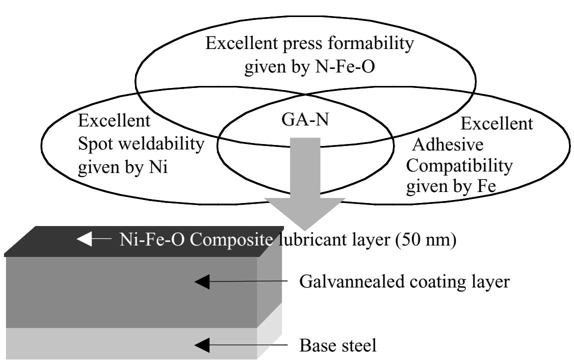

Fig. 8 Basic concept and cross sectional view of GA-N

the die and galvannealed coating layer) and adding Ni to improve affinity with press oil. Excellent weldability is obtained by preventing growth of the brittle Cu-Zn alloy which forms on the tip of the welding electrode[17].

The inorganic lubricant film of the GA-K sheet consists of Zn compounds fixed by a binder component. The Zn compounds greatly improve resistance to agglomeration anti-sticking property and impart a high sliding property, while the binder not only fixes the film, but also has the function of improving adhesion by increasing wettability and compatibility with various adhesive agents. In addition to providing a combination of excellent sliding and adhesive properties, the inorganic treatment film can be formed on GA coating layer by coating the treatment chemical followed by drying with a conventional drier, and thus can be manufactured easily using general roll coater equipment.

Table 1 shows the total performance of GA-N and GA-K in comparison to the double-layer GA and the conventional GA.

(2) Organic Solid Lubricant Technology[18]

Both GA-N and GA-K use an inorganic lubrication technology which gives a sliding property similar to that of double-layer GA. JFE Steel has also succeeded in developing a technology which imparts an even higher sliding property using an organic solid lubricant treatment technology. The developed material enables more complex and severe press forming. The strength and toughness of the film are improved by increasing the glass transition temperature (T_g) of the organic resin, while the sliding property and die galling property are improved by adding zinc phosphate and polyethylene wax. This technology is extremely effective not only with GA, but also in press-forming of hot rolled steel sheets.

(3) Summary

From the viewpoint of supplying easy-to-use materials, the development of improved lubrication technologies plays an important role on the material development side. All of the technologies introduced here

Table 1 Performances for automotive use of GA-N, GA-K, double layer GA and GA

Products	Press-formability	Weldability	Adhesive compatibility	Phos-phatability
GA-N	Excellent	Excellent	Good	Good
GA-K	Excellent	Good	Excellent	Good
Double layer GA	Excellent	Good	Good	Good
GA	Good	Good	Good	Good

have been widely adopted by customers, and have also been recognized as completed technologies, as seen in the 2001 Technical Development Prize of the Japan Institute of Metals[14].

2.2.2 Hot dip galvanized steel sheet with excellent surface appearance

The hot dip galvanized steel sheets (GI) have the advantage of low manufacturing cost in comparison to the electrogalvanized sheets, but the improvement of surface quality problems and various other quality properties related to assembly of the auto body was necessary. This report describes a manufacturing technology for GI which solves these problems and has been applied successfully to automobile outer panels, together with the quality features of this product.

(1) Improvement of Surface Appearance

One of the quality problems for the GI products exists in dross adhering to the sheet which causing surface defects after press forming. Dross can be classified into Fe-Al type dross (floating dross) and Fe-Zn type dross (bottom dross), which consist of intermetallic compounds of Fe eluted from the steel strip into the bath and Al or molten Zn in the bath. It is known that the formation of dross of both types is significantly influenced by Al concentration in the bath and the bath temperature[19-21].

The GI and GA are frequently manufactured using only one zinc pot. Because the Al concentration in the bath increases when the GA bath is changed to the GI bath, floating dross frequently occurs in this case. The reaction is shown below.

$$2FeZn_7 \text{ (bottom dross)} + 5Al \rightarrow Fe_2Al_5 \text{ (Floating dross)} + 14Zn$$

In the continuous galvanizing line (CGL) at West Japan Works (Kurashiki District), a second zinc pot was added in Nov. 2001, enabling production with exclusive-use pots for the GA and GI baths. This eliminates the switch of baths and makes it possible to produce the respective products under stable bath conditions, minimizing the amount of dross generated. As shown in **Fig. 9**, the number of dross adhering to the strip has decreased significantly, achieving

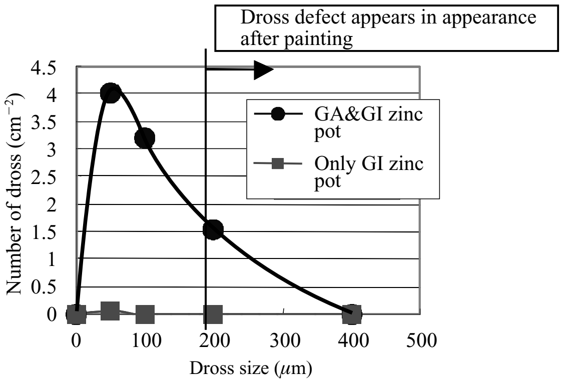

Fig. 9 Number of dross on galvanized steel sheet

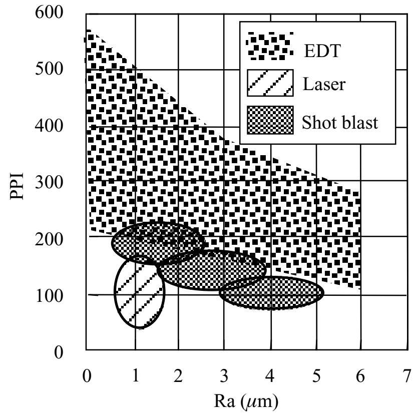

Fig. 10 Influence of skin-pass roll texturing technology on PPI and roughness

production of GI with satisfactory appearance.

At the same line, a technique for preventing the wavy flow-shaped pattern called bath wrinkle was established by proper control of wiping conditions (wiping pressure, nozzle-to-strip distance, nozzle height above the bath surface).

Production of sheets with an extremely small spangle size has also become possible by setting the Pb content of the zinc bath at the lower limit and controlling the strip cooling rate above the zinc pot.

(2) Surface Roughness Transfer Technologies and Frictional Properties

Surface roughness is controlled mainly by changing the surface roughness of rolls used in skinpass rolling and the rolling load and tension of the skinpass mill. At the cold strip mill at JFE Steel's West Japan Works (Kurashiki District), in addition to the existing roll texturing equipment, which included shot dull texturing and laser dull texturing devices, electro discharge texturing (EDT) was introduced in Dec. 1999. **Figure. 10** shows the available texturing range with these respective devices. The EDT has a wide texturing range with multiple roughness indexes, including R_a, PPI, and W_{CA}, and also reduces deviations.

Figure. 11 shows the coefficient of friction obtained in the conditions that a 1.5 g/m^2 coating of wash oil

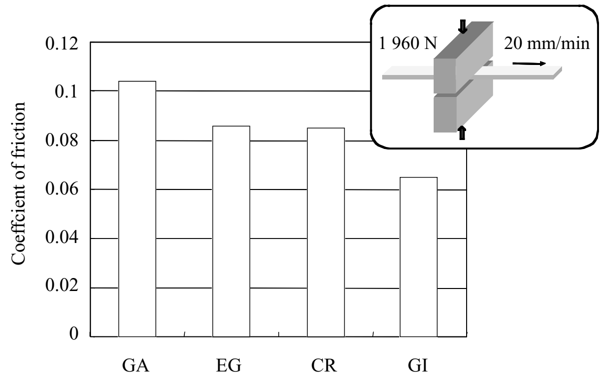

Fig. 11 Influence of coating type on coefficient of friction

is applied to GA, electrogalvanized steel sheet (EG), cold rolled steel sheet (CR) and GI, and die blocks of SKD1 steel (length in sliding direction: 20 mm, width: 20 mm) were pressed on the surface of the sample sheets with a force of 1 960 N and plane sliding was performed at 20 mm/min. It is be understood that GI has a low coefficient of friction and high sliding property in comparison to GA, EG and CR.

(3) Summary

Stabilizing bath conditions by installing a pot exclusive to GI and optimizing the manufacturing conditions has made it possible to manufacture GI with minimal dross adhesion and satisfactory surface appearance. Using a recently-introduced electro discharge texturing (EDT) technology to modify the roll roughness profile, it is possible to transfer surface roughness with excellent frictional properties.

2.3 Evaluation and Application Technologies for Automotive Steel Materials

2.3.1 Tailor welded blanks

Tailor welded blanks (TWB) are those in which sheets of different thickness and/or properties are joined by laser, seam or plasma welding before press forming. Since TWB makes it possible to manufacture parts with the optimum arrangement of materials using a smaller number of press dies, it is an indispensable production technology for realizing high performance and weight reduction in automobiles (**Fig. 12**).

From the viewpoint of TWB formability and appearance, laser welding is advantageous. However, to obtain sound welds, the accuracy of the alignment of the blanks to be welded and the laser welding position must be controlled less than 0.1 mm level.

The forming behavior of the TWB material can basically be classified into the 2 cases by the direction of the major strain to the weld line. In the case of the major strain occurs the parallel direction to weld line, the general formability of the blank can be arranged using the sum of the welded portion hardness and the base mate-

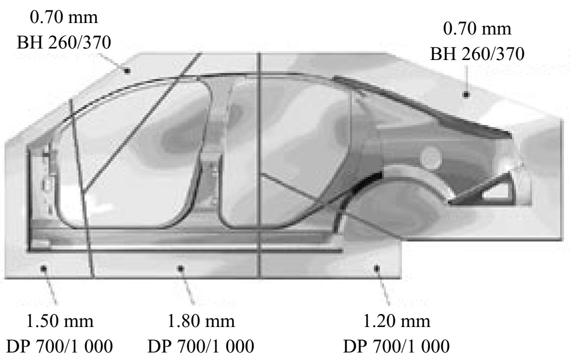

Fig. 12 Application of TWB (ULSAB-AVC project)

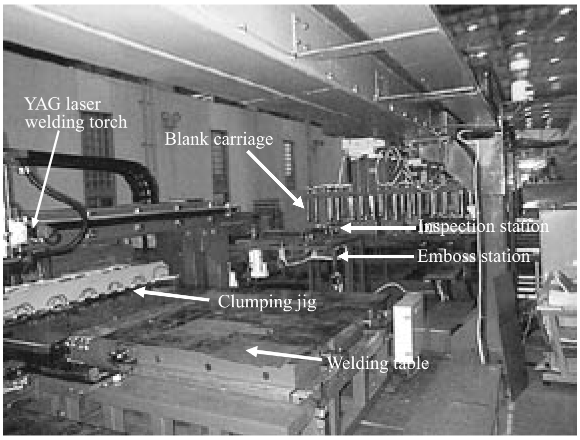

Fig. 13 Appearance of TWB equipment

rial hardness as a parameter, because the either ductility of the base material or the welded portion govern the formability. Furthermore, ductility of the welded portion can be arranged by the composition (carbon equivalent) of the base material. On the other hand, in the case where major strain is generated in perpendicular to the weld line, formability is determined by the balance of material strength and thickness. Based on the above knowledge, JFE Steel optimizes the welding position of TWB by using FEM (finite element method) simulations. Taking advantage of its knowledge of welding and TWB material forming behavior, as mentioned above, JFE Steel began a TWB business in 2001 (**Fig. 13**). It has also established technologies for optimizing material arrangement and predicting rigidity and high speed deformation behavior of the parts manufactured using TWB, and has created the material databases necessary for forming simulations, such as FLD for TWB manufactured by the company.

2.3.2 Application technologies of hydroforming

In contrast to the traditional hydroforming (HF) technology, the new HF, as illustrated in **Fig. 14**, is a forming technology in which a material tube is first subjected to various pre-forming processes such as bending to a shape approximating that of the final product, press-crushing and diameter reduction, followed by insertion into a die and forming to the specified die shape by applying internal pressure while imparting axial force by means of an axial feed head which is used both as a seal for the tube end and as a feed hole for high pressure water.

Among the numerous advantages of HF parts in comparison to the parts manufactured by sheet metal/welding methods, HF parts have high strength and rigidity owing to their unitary structure, enable weight reduction by omission of welding flanges and more rational sectional design and realize cost reductions by part integration, reduced die costs and welding work.

However, for various reasons, this technology is more widely used in Europe and the United States than in Japan. The most important tasks for achieving the same level of acceptance in Japan are a reduction of equipment costs and a large reduction in cycle time. A steady progress can be seen in this respect, as various new HF machines have recently been developed, and the cycle time has been reduced to less than the 20 s level. From the technical viewpoint, the following can be mentioned as key items for successful HF: (1) optimization of HF processes with the pre-forming and establishment of the evaluation system of forming allowance, (2) optimization of the loading path and adequate control technology, (3) development of tubes with high HF formability, and (4) lubrication.

Elucidation and development of tube properties favorable for HF application are also progressing steadily. Although the material with high elongation relative to the required strength is desired, high n-values are used in alleviating localized deformation in the transverse section, while the influence of r-value is increasingly important under severe axial feeding conditions. High r-values are also desirable for alleviating circumferential thickness deviation in pre-bending parts. From this viewpoint, the CBR mill for low strain pipe-making developed by JFE Steel can be considered a suit-

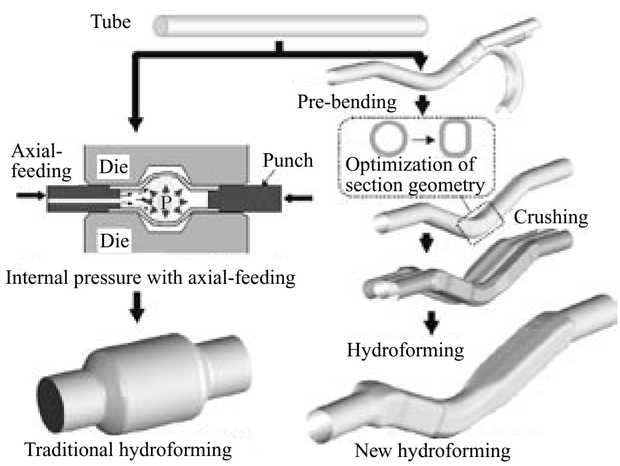

Fig. 14 Manufacturing process of hydroformed tube

able process for HF applications. JFE Steel's HISTORY (high speed tube welding and optimum reducing technology) steel tube is manufactured by warm reduction of the diameter of an electric resistance welded (ERW) tube, as discussed later in this paper. Because the HISTORY tube has high *r*- and *n*-values and is free of seam hardening, it shows excellent HF formability.

2.3.3 Application technologies for high strength steel sheets in press forming

To meet the needs of safety and weight reduction, particularly in auto parts, higher strength has been desired in materials. However, from the viewpoint of formability, a variety of press forming defects tend to occur more easily when high tensile strength steel is used, including material rupture, wrinkles and surface deflection, and poor dimensional accuracy.

On the material side, development of steel materials with higher performance and high lubrication steels which compensate for reduced formability is continuing with the aim of preventing rupture, wrinkles and surface deflection. On the forming technology side, development of new forming technologies such as hydraulic counter pressure forming and tension control forming as well as advance prediction technologies for forming defects utilizing numerical simulation techniques, is underway. **Figure 15** shows a high pressure liquid lubrication forming method proposed by JFE Steel as a new forming technology. With this forming technology, parts are formed while supplying a liquid from the die at high pressure, reducing friction between the material and the die, which prevents cracking, while at the same time also preventing flange wrinkles. A rapid progress has been achieved in numerical simulation techniques, and highly accurate prediction of fracture in the forming of actual parts is now possible. JFE Steel is also developing a method of surface deflection predicting. Although its quantitative accuracy is still inadequate, this technology has reached a level where qualitative prediction is possible.

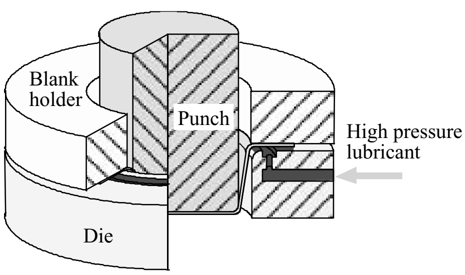

Fig. 15 High pressure liquid lubrication method

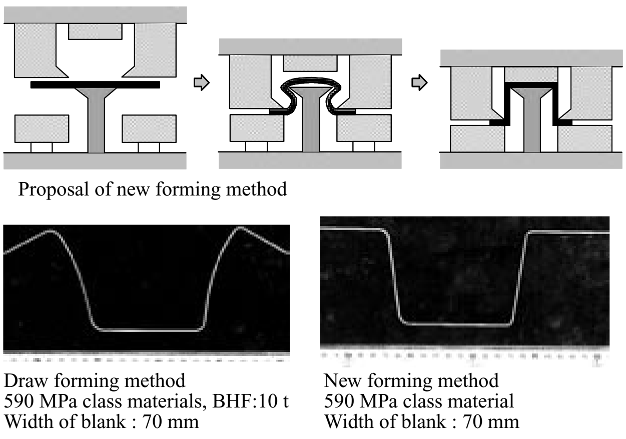

Fig. 16 Proposal of new forming method for improving shape fixability

The most important problem in forming automotive structural parts is dimensional accuracy in the formed parts. The countermeasures to this problem now being studied from the viewpoint of forming technology include the methods of reducing springback by adopting tension control forming or changing the forming mode from drawing to bending. The methods of optimizing the die shape using numerical simulation are also under study. **Figure 16** shows an example of the results of a tension control forming technology using an optimized die profile (1997 proposal). With simple profiles, it was found that dimensional accuracy equal to that of mild steel materials can be obtained with a 980 MPa material. JFE Steel is now extending this technology to more complex shaped parts.

2.3.4 Application of CAD-CAE systems

A significant progress has been achieved in the computer-based simulation technologies in recent years through the development of advanced finite element method (FEM) techniques and improvement of computer performance, making it possible to apply simulation techniques to the analysis of press-forming and other processes which had been difficult with the conventional methods. Car makers are also making extensive use of these technologies as tools for studying the functions and press-formability of parts in the auto body development process. JFE Steel has introduced multi-use CAE systems that cover a full-range of the auto body development, for example CAD data processor available to auto body design data, FEM simulation systems with pre-/post processor, and has created an environment where databases can be shared with car makers. This is contributing to shorter lead time in auto body development, expanded application of high strength steel sheets, etc. In press formability analysis using FEM, the occuring of split and wrinkles can be predicted, but for spring-back analysis, improvement of accuracy is still necessary. For the impact analysis, the creation of databases for stress-strain behavior at high strain rates has made the highly accurate simulation possible. For the needs of further accurate analysis, strain distribution changes during

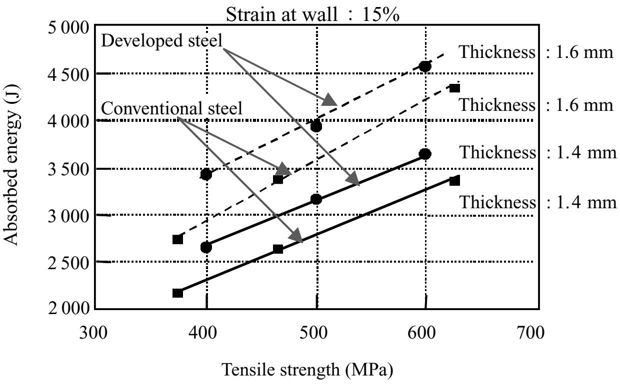

Fig. 17 Improving crashworthiness of hat square column by using new developed material

Fig. 18 Result of numerical crash simulation of hat square column

forming and heat influences of subsequent paint baking process have to be considered. **Figures 17** and **18** show the examples of impact analysis which take into account deformation during forming with conventional steel sheets and a newly developed one which displays a significant increase in strength as a result of paint baking after press forming. JFE Steel is also studying the problem of surface deflection, which causes minute irregularities on the panel surface, galling caused by stress in the thickness direction of sheet, and similar problems.

3. High Frequency Electrical Materials for Cars of the Future "Super-Core"

The cars of the future, including not only hybrid cars and fuel cell cars, but also general gasoline-fueled vehicles, are expected to include a large number of onboard electric and electronic parts, and in particular, parts for converter/inverter power conversion devices.

A high frequency design should be adopted to downsize these parts for mounting in the limited space available in an automobile, and lighter weight and lower noise are strongly demanded as well. Wasteful use of limited energy supplies must also be avoided, and parts must be able to withstand service conditions from extreme winter cold to high temperatures.

JFE Steel's Super-Core, which is a core material based on a 6.5%Si-Fe alloy, is already beginning to be adopted in high frequency parts in the electric/electronic industries. The following describes its application to automotive parts.

3.1 Features of JFE Steel's Super-Core

3.1.1 JNEX

The JNEX is a non-oriented electrical steel sheet which contains 6.5% Si dispersed uniformly in the sheet thickness direction. As shown in **Fig. 19**, electrical sheets show their highest levels of magnetic properties at a Si content of 6.5 mass%.

From the viewpoint of automotive applications, the most important feature of JNEX is zero magnetostriction. Thus, simultaneously with contributing to low noise, JNEX is also resistant to work strain. Because its temperature coefficient is extremely small, it also has the distinctive feature of minimal changes in magnetic properties in the range from cryogenic temperatures to 150°C.

3.1.2 JNHF

The JNHF is a highly gradient Si steel sheet with a 6.5% Si content only in the steel surface layer, and the Si content decreases in the direction toward sheet interior. In the high frequency range of 10 kHz, its core loss, in other words, sheet energy loss, is lower than that of JNEX. Both JNEX and JNHF can be used without concern about damage due to vibration, such as that which occurs in ferrite cores.

3.2 Automotive Applications

3.2.1 Stationary equipment

As the cores for reactors with high electrical capacity converter/inverter filter circuits which use IGBT semiconductor elements, JNEX is an optimum material which realizes low noise and high efficiency.

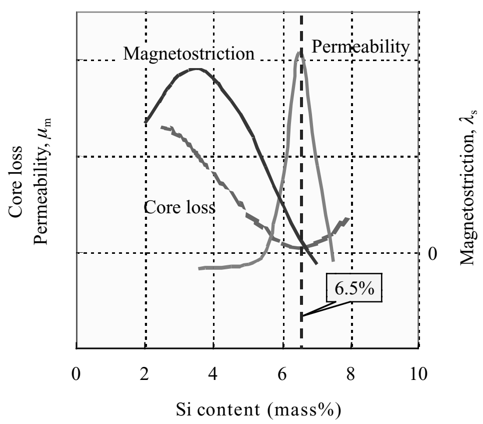

Fig. 19 Variation of magnetic characteristic by Si content of Fe-Si alloy

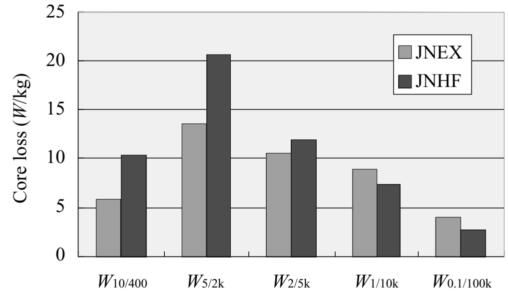

Fig. 20 Core loss comparison data between JNEX and JNHF

In particular, the low magnetostriction JNEX is unaffected by the conditions in which stress is applied to the core after fixing, for example, when a resin molding is used for insulation protection, and therefore is free of property change and similar problems.

Since JNHF has lower core loss than JNEX, it is the optimum material for the applications in which cores are used in the frequency range higher than audible frequencies, where noise is not a problem.

3.2.2 Rotating machinery

In the generators and motors of the future, it appears likely that high torque and extreme reductions in size and weight will be required due to the increase in the number of poles.

In motor cores, it is necessary to reduce core loss in a wide range of frequency distributions to cope with the high frequency ripple generated by converter/inverters, as well as in the basic frequency components of rotation. As shown in **Fig. 20**, JNEX is an outstanding product for this purpose with low core loss over the range from 1 kHz to 20 kHz. The 0.1 mm thick JNEX is already used in the cores of micro turbine generators.

3.2.3 Other electrical applications

The conventional mechanical and hydraulic drive devices are currently being superseded by electromagnetic actuators, and as hydraulic piping is replaced by copper wiring, current transformers (CT) are now essential items. The current transformers must measure DC current values including high frequency components under severe temperature conditions. The JNEX is also expected to demonstrate excellent properties in cores for CT.

3.3 Summary

An increasingly diverse range of electric and electronic parts are now being used in large numbers in automobiles, in applications from drive trains to lightning and audio equipments. As an iron core material for high frequency devices, JFE Steel's Super-Core not only provides outstanding performance in essential magnetic properties, but also has excellent properties in the characteristic service environments of automotive applications, and is therefore expected to be widely used in this field.

4. Ferritic Stainless Steels for Automobile Exhaust System Parts

Ferritic stainless steels are used in automotive exhaust system parts because they possess excellent corrosion resistance and high temperature properties. They are more economical than the austentic stainless steels, which contain large amounts of expensive Ni, and have small thermal expansion coefficients. Since the properties required in the exhaust system differ greatly depending on the part, JFE Steel has developed, produces, and sells many grades of stainless steels shown in **Table 2** in order to meet each requirement.

4.1 Steels for Mufflers

The primary property required for mufflers is corrosion resistance. Inside the muffler, a severe corrosion environment exists due to the formation of a strongly corrosive condensate by condensation of NH_4^+, CO_3^{2-}, SO_4^{2-}, Cl^-, organic acids and other substances originating in components of the exhaust gas. On the outside of the muffler, corrosion caused by adhering sea salt particles and road deicing salt is a problem. **Figure 21** shows the results of measurements of the maximum perforation corrosion depth after a synthetic condensate corrosion test simulating interior corrosion of steel sheets used in mufflers[22)] and the maximum corrosion depth in a cyclic corrosion test simulating corrosion of the outside of the muffler, using the same materials.[23)] Cr and Mo are effective against both types of corrosion. Accordingly, the low Cr JFE409L steel is used in parts where corrosion resistance requirements are not severe, while JFE439L which contains 17.5% Cr, or JFE 432LTM and JFE436LT in which corrosion resistance is further improved by Mo addition, are used in parts with severe requirements.

Table 2 Examples of chemical composition of steels

(mass%)

JFE Steel's standard	Cr	Si	Mo	Others
JFE409L	11	0.3	–	Ti/0.21
JFE439L	18	0.1	–	Ti/0.29
JFE432LTM	18	0.1	0.5	Ti/0.29
JFE436LT	18	0.1	1.1	Ti/0.29
JFE429EX	15	0.9	–	Nb/0.44
JFE-MH1	15	0.3	1.6	Nb/0.50
JFE4 30LNM	17	0.3	0.5	Nb/0.36
JFE434LN2	19	0.3	1.8	Nb/0.34
JFE20-5USR	20	0.2	–	Al/5.8, La, Zr

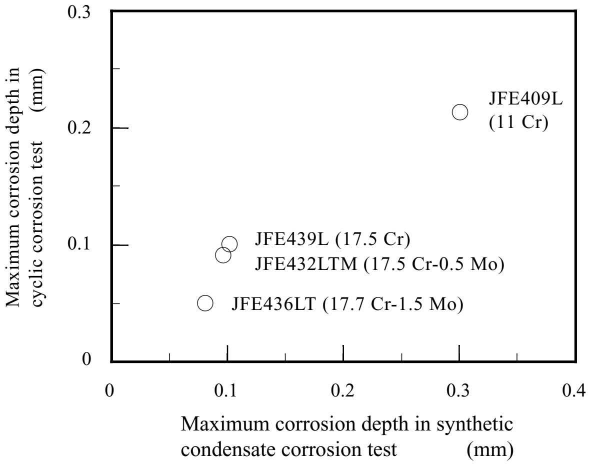

Fig. 21 Comparison of corrosion resistance between steels for muffler

4.2 Steels for Exhaust Manifolds

The exhaust manifold collects high temperature combustion gas discharged from engine cylinders and leads it to the front pipe. Therefore, in comparison with other parts, higher temperature properties are required. Car makers are strongly promoting improved exhaust gas purification performance and fuel economy, which can be achieved effectively by increasing engine combustion temperature and weight reduction. Although castings have conventionally been used as exhaust manifolds, against the foregoing background, car makers are progressively substituting high heat-resistance, thin-gauge stainless steel pipes or press formed products in place of cast iron products[24]. **Figure 22** shows the relationship between the *r*-values and the proof stress at 800°C for the stainless steels used as an exhaust manifold. The JFE409L is used in low temperature applications, while JFE430LNM with improved high temperature strength obtained by Nb addition is used in high temperature applications. In many cases, high formability is also required in order to design complex manifold shapes to fit the limited space of the auto body. In response to this need, JFE Steel established a high *r*-value technology for ferritic stainless steel and developed JFE429EX with a dramatically improved *r*-value[25,26]. Based on the compositon of JFE429EX, the company also developed JFE-MH1, in which high temperature strength is further improved by Mo addition and optimization of the Si content[27,28]. These developed steels are beginning to be adopted by car makers.

These steel grades are suitable not only for exhaust manifolds, but also for other high temperature parts such as the front pipe and converter case.

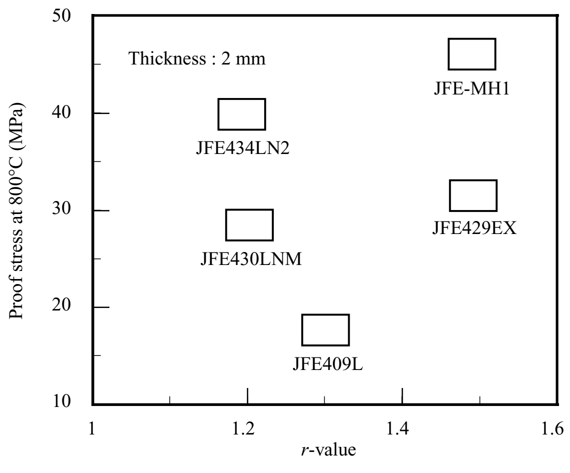

Fig. 22 Comparison of *r*-value and PS at 800°C between steels for exhaust manifold

4.3 Steels for Catalytic Converter Substrate

Conventionally, ceramics were the mainstream material for catalytic converter substrate. However, to meet stricter exhaust gas regulations, metal substrate of ferritic stainless steel foil with high thermal impact properties and a low heat capacity are now being used. The metal substrate has a honeycomb structure of Fe-20%Cr-5%Al alloy foil with the thickness of 20–50 μm and supports a catalyst on its surface to purify exhaust gas. Because the substrate is heated to a high temperature by exhaust gas, high oxidation resistance is required for the foil material. In JFE20-5USR, the growth rate of alumina film which forms at high temperatures is extremely decreased by adding a small amounts of La and Zr[29], so that the life of the catalytic converter is extended.

5. Steel Tubes

5.1 HISTORY Tube

The HISTORY (high speed tube welding and optimum reducing technology) tubes, as shown in **Fig. 23**, have an advantage of high *r*-value in the axial direction in comparison to the conventional electric resistance welded (ERW) tubes,[30] and therefore has high bending formability and tube hydroformability,[31] making it suitable for applications such as automobile undercarriage parts which require complicated, severe forming due to part integration in trailing arms and similar components. As shown in **Fig. 24**, HISTORY tubes can be manufactured with high dimensional accuracy, and in particular, with a low thickness deviation ratio,* in the small-diameter, thick-wall size range, which had been difficult to manufacture with conventional ERW pipemaking technology.[32] Small-diameter, thick-wall HISTORY tubes with low thickness deviation have excellent fatigue properties, including torsion properties. These tubes are suitable for use in weight reduction applications where steel bars have been used conventionally, such as stabilizers and drive shafts, which require high fatigue strength,

* $(t_{max} = t_{min})/t_{ave}$, t: Wall thickness

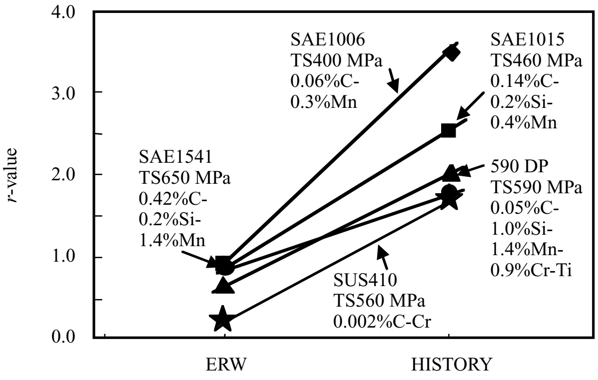

Fig. 23 *r*-value of the HISTORY steel tube

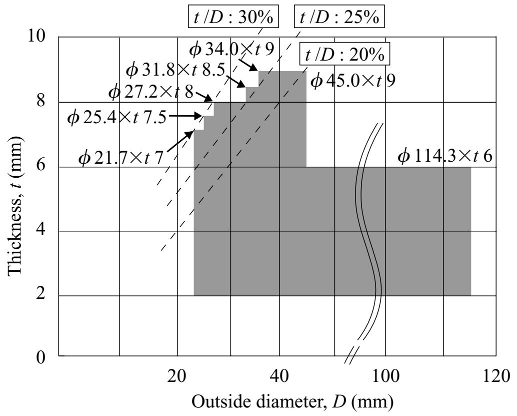

Fig. 24 Available manufacturing size of the HISTORY steel tube

and can be applied in the as-reduction rolled condition.

These advantages of the HISTORY tubes are obtained by applying a heating and reducing process to the ERW tubes which was developed by JFE Steel. For example, the high *r*-values in the axial direction were achieved by applying warm reducing for the first time in the world.[33)] Even with low carbon steel, high carbon steel and other base steel materials in which the high *r*-values are difficult to obtain in sheets using the conventional recrystallization texture method, the high *r*-values in the axial direction can be obtained in HISTORY tubes by achieving a designated rolling texture, which is realized by reducing the tube in the warm region. The high dimensional accuracy of the HISTORY tubes, and in particular, their low thickness deviation ratio, are obtained using a newly developed 4-roll reducer. Rolling large diameter, thick-wall ERW tubes, which are relatively easy to manufacture, to a small diameter with this 4-roll reducer makes it possible to produce small-diameter, thick-wall tubes with high dimensional accuracy, which had been difficult with the conventional technology.

5.2 High Formability ERW Tubes for Automotive Use

Generally, the parts which are formed from steel

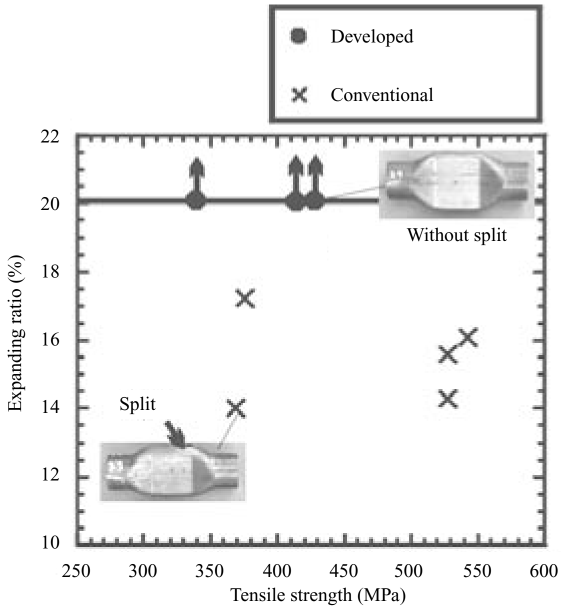

Fig. 25 Relationship between tensile strength and tube hydroformability of the developed and the conventional tubes in rectangular die cavity (Maximum expanding ratio = 20%)

tubes by plastic working such as tube hydroforming (THF) have a complex strain history, which includes pipemaking process, pre-forming by bending and die reduction, the THF process as such and other steps. Therefore, simultaneously with maximizing the formability of the material steel sheet before pipemaking, it is also important to design the material properties which are specific to the steel tube in a way that minimizes the decrease in formability due to this strain history in all the steps through the final forming process.

This section presents an example of the properties of a JFE Steel high formability ERW tube[34)] where solute N, which has a negative effect in formability reduction due to strain history, is excluded from the material by controlling the chemical composition of material steel band and hot rolling conditions.

Figure 25 shows the relationship between tensile strength and the maximum expansion ratio in THF in a rectangular die cavity at a maximum circumferential expansion ratio of 20% with the developed steel, in which solute N is excluded from the material band, and a conventional material containing residual solute N. In all the cases, the developed steel was expanded to the maximum expansion ratio of 20% without splitting, giving a high rupture limit in comparison to the conventional material.

JFE Steel is engaged in the product development to meet the need for high strength materials exceeding the present 590 MPa in high formability ERW steel tubes. In the material property design and base material selection for high strength materials, it is important to consider not only formability, but also the total balance of product properties including impact properties, fatigue strength, chemical conversion treatment properties, etc.

5.3 Stainless Steel Tubes for High Temperature Service in Automotive Exhaust Systems

Improvement in the exhaust gas purification rate in automobiles is strongly required in response to stricter legal regulations in many countries. The technologies which accelerate the exhaust gas purification reaction by raising the exhaust gas temperature have been applied as a countermeasure, but as a result, high heat resistance is now required to the materials for exhaust manifolds. Furthermore, in some cases, the catalytic converter used in exhaust gas purification is located near the engine to realize operation at higher temperatures, but this reduces space in the engine compartment. As a result, the shape of the exhaust manifold, which must be designed to fit into this limited space, has become increasingly complex. Therefore, high formability, including small radius bending and high pipe expansion ratios, is also required for manifold materials. JFE Steel developed JFE-MH1 for response to these needs.

Among high temperature properties, the high temperature strength of JFE-MH1 is superior to that of JFE429EX and equal to that of JFE432LN2 (SUS444). In manufacturing stainless steel tubes for automotive exhaust system use, JFE Steel uses high *r*-value steel sheets as material for pipemaking, and produces tubes with excellent formability by using the CBR, which is a low-strain forming method developed independently by JFE Steel. **Table 3** shows the mechanical properties of JFE Steel's ERW products for exhaust system use. The formability of JFE-MH1 is superior to that of JFE434LN2 (SUS444) and approximately equal to that of JFE429EX.

Since the newly developed stainless steel tubes for high temperature exhaust system use, JFE-MH1, are suitable for high temperature parts of the exhaust system and possesses high formability, their application is expected to expand in response to stricter automotive exhaust gas regulations and thus to contribute to environmental purification.

Table 3 Mechanical properties of ERW pipes according to JIS11

	Size	YS(MPa)	TS(MPa)	El(%)
JFE-MH1	ø38.1×2.0	513	543	46
JFE429EX	ø38.1×2.0	506	529	45
JFE434LN2	ø48.6×2.0	547	573	38

6. Bar Products for Automotive Use

6.1 Bearing Steels "NKJ", "KUJ7"

Bearings are essential components in the rotating drive systems of industrial machinery and automobiles. Bearings are being progressively downsized, but they must still provide service life equal or superior to that of the conventional ones. JFE Steel focused on the maximum dimension of non-metallic inclusions in the steels, which have remarkable effect on the service life of bearing. JFE Steel also established the manufacturing process which controled these inclusions to small size.

In addition to such approaches, JFE Steel has also clarified the effect of chemical compositions on preventing the microstructural damage in rolling contact fatigue condition. Based on the innovative material design, it developed and commercialized the medium carbon bearing steel (NKJ steel) and the bearing steel with extended rolling contact fatigue life for the intermediate temperature use (KUJ7 steel, **Fig. 26**).

6.2 Graphite Steel "HFC1 Steel"

Good machinability is required for the steel in the manufacturing processes of automotive and OA parts. The machinability of steel can be improved by adding Pb to steel. However, Pb is one of the quite harmful elements for the environment. Considering such situation, the needs for Pb-free steels are increasing. By optimizing the chemical composition, it is possible to precipitate graphite in steels for machine structural use with hypoeutectic compositions. Utilizing graphite precipitation in steel, the balance of machinability and cold forgeability superior to that of the conventional steels were achieved without using Pb (**Fig. 27**). This steel also has the enough fatigue strength after quenching and tempering. The developed steel shows particularly outstanding properties for the applications to the process consisting of cold forging and machining, followed by quenching and tempering.

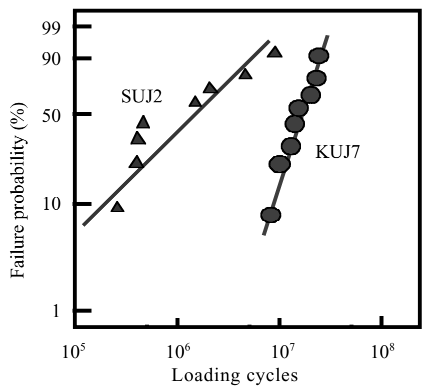

Fig.26 Rolling contact fatigue life at 180°C

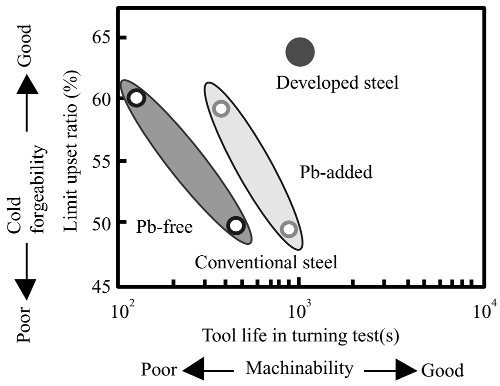

Fig. 27 Relation between machinability and cold forgeability

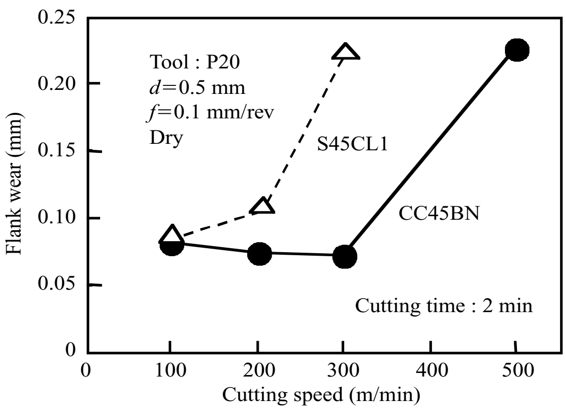

Fig. 28 Comparison of flank wear

6.3 BN Free Cutting Steel "CCBN Steel"

The BN free cutting steel, in which hexagonal BN crystals are formed by adding more than 50 ppm of B and more than 100 ppm of N, is a new type of the Pb-free free cutting steel with machinability equal or superior to that of the Pb-added free cutting steels over a wide range of cutting conditions from low speed drilling to high speed cutting with carbide tools. **Figure 28** shows the relationship between flank wear and cutting speed in cutting with a carbide tool. Since wear properties are satisfactory, this material is recommended for high speed cutting applications.

In terms of the size, BN is similar to MnS. Therefore, the mechanical properties, fatigue properties, cold and hot forgeability and other properties of BN free cutting steel are virtually equivalent to those of the base steel before BN addition.

6.4 High Surface Durable Carburized Dual-phase Steel

Anti-temperability (degree of resistance to softening due to tempering) is improved by adding Si, Cr and other elements to JIS case hardening steel, as shown in **Table 4**, and as a result, the gear surface shows a good pitting durability. Furthermore, the A_{c3} transformation point can be increased by adding Si and V while reducing Mn, resulting in a dual-phase structure of ferrite and martensite in the internal structure after case hardening at ordinary temperatures. (In this case, the carburized region consists of a single phase of martensite.) Accordingly, deformation due to hardening after carburization is slight, realizing low strain together with high surface durabilites.

Table 4 Example of chemical composition

(mass%)

C	Si	Mn	P	S	Cr	Mo	Nb	V
0.23	1.75	0.42	0.016	0.010	1.52	0.38	Add.	Add.

By using a combination of carburization and shot peening, it is possible to obtain a high surface durabilites, more than 15% superior than of current gears.

This steel can be applied to all types of carburized gears including mission and differential.

6.5 High Toughness Microalloyed Steel for Hot Forging

The high toughness microalloyed steel for hot forging has a dual-phase microstructure (ferrite-pearlite) which provides the same performance as the conventional quenched and tempered steel when used as-forged (without heat treatment). The amount of Ti addition is optimized to suppress grain growth during heating before hot forging, and precipitation strengthening is obtained by adding V to a low C, high Mn (0.3%C-1.45%Mn) base material, securing strength and toughness in the as-rolled condition.

This steel is applied to undercarriage parts (knuckle, etc.) and companion flanges.

7. Warm Compaction Method with Die Wall Lubrication for Iron Powder Metallurgy

Required fatigue strength in sintered automotive parts has increased year by year. The most effective method for increasing fatigue strength of sintered parts is densification.

JFE Steel therefore developed a warm compaction method with die wall lubrication (**Fig. 29**), by combining a die wall lubrication method in which a powder lubricant is applied to the die wall by electrostatic coating and a warm compaction method in which the iron powder and die are heated to 100–150°C. Since this method makes it possible to reduce the content of internal lubricant, which has a low specific gravity of approximately 1, the density of sintered compacts can be increased by approximately 0.2 Mg/m^3 in comparison to the conventional compaction method (single-compaction and sin-

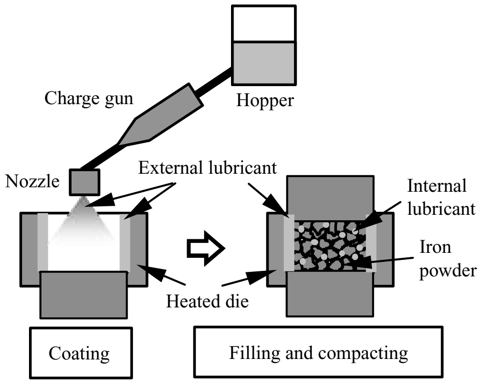

Fig. 29 Schematic diagram of warm compaction method with die wall lubrication

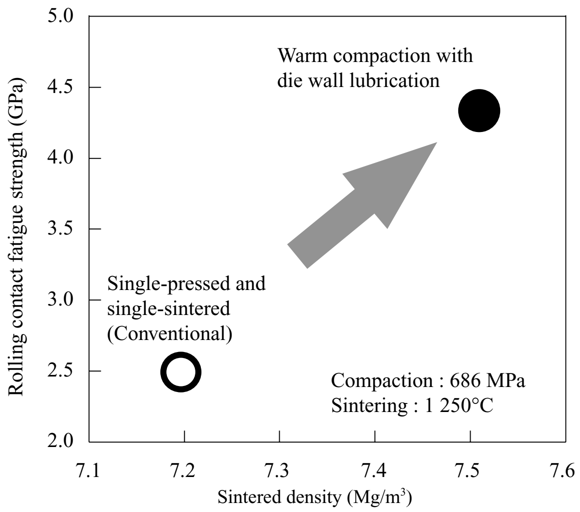

Fig. 30 Relation between sintered density and rolling contact fatigue strength of sintered and carburized steel compacts made of 2Ni-1Mo partially alloyed steel powder

gle-sintering method).

Figure 30 shows the rolling contact fatigue strength of the high density sintered and carburized steel compacts of Sigmaloy 2010 (2Ni-1Mo partially alloyed steel powder) produced by the warm compaction method with die wall lubrication. For the conventional compaction, the rolling contact fatigue strength was 2.5 GPa at a sintered density of 7.2 Mg/m^3, while in contrast, the compacts manufactured by the warm compaction with die wall lubrication showed a significant increase in strength, to 4.4 GPa at 7.5 Mg/m^3.

In the future, this compaction method is expected to be applied to the production of the parts requiring high fatigue strength in the automotive industry.

8. Lightweight Composite Material for Automotive Headliner "KP Sheet"

The KP Sheet is a composite material for press forming use consisting of glass fiber (GF) and polypropylene (PP). It is manufactured and sold by a JFE Steel Group member, K-Plasheet Co. It has attracted an attention for its light weight, good formability and shape stability. Since around 1997, it has been widely adopted as automotive interior parts, particularly as a base material for formed headliners.

As a distinctive feature of KP Sheet, GF and PP are uniformly dispersed in the material. This is achieved by a special manufacturing method called the "papermaking" method,[35] in which GF and PP are first dispersed in a foam, and a non-woven-like intermediate product called web is obtained by a continuous papermaking technique similar to that used in the actual papermaking. The distribution of the GF in the web is not limited to a 2-dimensional plane, but is also oriented in the thickness direction, giving KP sheet its characteristic high expansibility. The web is pressed into dense consolidated sheets in a pressing process, and then cut and finished for supply to customers.

When the PP is melted by heating the KP Sheet in an infrared oven, the entire sheet expands uniformly due to the springback of GF, giving the sheet formability. Utilizing this property, large, lightweight and high rigidity parts can be manufactured very easily. Moreover, since a formed product with a thickness 2–4 times that of the original KP Sheet can be obtained as a result of the expansion property, it is possible to form high rigidity parts with a greatly increased second moment of area.

Since the elastic slope, which is an index of rigidity in headliner base materials, is correlated with the second moment of area,[36] the materials with higher expansion ratios are advantageous for improving rigidity. In a new product, KP Sheet UL, which was developed in 2001, the expansion ratio is increased by as much as 30%, and as a result, the elastic slope is 1.5 times greater than that of the conventional product, at 7.2 N/mm (formed thickness: 4 mm) with unit weight of 800 g/m^2. This means that a weight reduction of 20% can be achieved with the same elastic slope, making KP Sheet UL an outstanding product for either part weight reduction or improved rigidity performance. An acoustic product with a high sound absorbing property is also under development.

9. Conclusion

This paper has introduced JFE Steel's wide range of steel products for automotive use. And evaluation and application technologies of the steel products being applied to the EVI (early vendor involvement) activities are also introduced. JFE Steel is committed to contribute to these technologies for the effective manufacturing at automotive industry.

Although this paper presented just an overview, JFE Steel plans to publish detailed reports on new automotive products and technologies in JFE Technical Report No. 4. JFE Steel would like to invites all of readers to read that issue.

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