Newly Developed Steel Sheets with New and Advanced Functions to Meet Customers' Needs*


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Synopsis:

Kawasaki Steel has presented newly developed steel sheets with new and advanced functions to each customer field. Such steels are developed timely based on the customers' needs grasped precisely by Kawasaki Steel. These are hot rolled steel sheets, cold rolled steel sheets and coated steel sheets. As the customers' needs are diversifying, the subjects to satisfy the contrary properties are increased. However, Kawasaki Steel has been tackling these subjects free from accepted ideas. In order to develop and provide the new steel sheets to satisfy the ecological requirements as the common needs for the human, it is very important that Kawasaki Steel considers together with customers.

1 Introduction

With world progress and evolution, general needs for the various commodities manufactured from steel sheets have become increasingly diverse. Accompanying this trend, customers requirement for the steel sheets have also become more diverse. Kawasaki Steel has supplied its customers with a large number of steel sheet products to meet these needs, and is also working to develop new products which it should supply in the mid- and long-term.

Conventional product development has frequently been conducted from the standpoint of "product-out", that is, based on the seed technologies of the material supplier. However, Kawasaki Steel has been focusing on "market-in" product development, in which the company attempts to develop the functions required by customers through close relationship with them. The self-lubricating steel sheet (River Zinc FS) which Kawasaki Steel developed in advance of the other steel makers is one example of market-in product development[1]. This product was developed in response to requests from employees of customers' press shop, to help keep their press shop clean. Specifically, press oil was being vaporized during press forming of steel sheets, creating a dirty environment throughout the press shop, including the floors and walls. Therefore, Kawasaki Steel developed this product to meet the need for a steel sheet that enables deep drawing without press lubricant oil. A degreasing treatment after a press forming had became unnecessary because a press lubricant oil was not necessary in a press forming. Incidentally, this was the birth of environmentally friendly product that was in line with the restriction of the fluorocarbon degreasing agent.

This report describes the steel sheets with new and advanced functions which Kawasaki Steel has developed to meet the needs of customers in the automotive, packaging, and electrical machinery industries.

2 Steel Sheets for Automotive Applications

In the past, public requirements related to automobiles centered around their operation and convenience. However, in recent years, emphasis has been placed on automobile related needs from two new directions. The first is preservation of the global environment, with respect to machines that consume fossil fuels and emit carbon dioxide. The second is improved safety in accidents, which have become more commonplace due to

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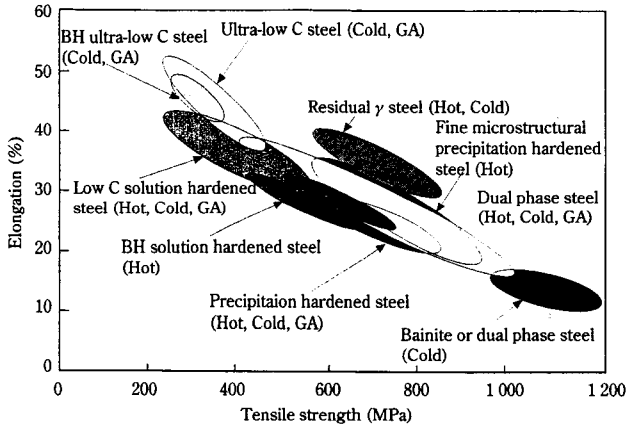

Fig. 1 Kind of steel for automotive use categorized after tensile strength and elongation

the excessive popularity of the automobile as a means of transportation. Reduction of auto body weight is one means of using fuel more efficiently (energy saving) while maintaining travel performance. However, auto weight has tended to increase due to the reinforcement of the auto body structure to increase the safety of occupants in case of a collision, and auxiliary devices that improve convenience (for example, air conditioners, motors for power steering and power windows, and audio equipment). How to satisfy both requirements, that is, reducing weight while also ensuring safety, is one of the most important tasks for auto makers.

Lightweight materials such as aluminum, magnesium, and plastics have been studied as materials for weight reduction. However, because a number of problems remain to be resolved with these materials, including recyclability, applicability, reliability, and economy, the most common material which makes up the auto body is steel sheets. Development of the steel sheet with high formability and also high strength is the greatest needs for the weight reduction of car body. High formability makes possible to form parts in one unit, and high strength makes possible to reduce the material thickness without sacrificing safety.

Figure 1 shows a summary of the automotive steel sheets which have been developed to date by Kawasaki Steel[2]. The various steels are categorized by their balance of strength (tensile strength) and formability (represented by total elongation in the tensile test). All of these steel sheets were developed and mass produced in response to the needs of auto makers. Typical steel types developed in Kawasaki Steel are introduced below.

2.1 Bake Hardening Type Cold Rolled Steel Sheets for Exposed Auto Panels

In the press forming stage, bake hardening sheets have low strength and high formability. After forming, however, BH sheets are strengthened by strain aging hardening through the paint coat is heated in the baking process. This gives them adequate dent resistance for exposed parts.

Table 1 Mechanical properties of surface-coated cold-rolled sheet steels with extra-deep drawability and bake-hardenability

Steel	YS (MPa)	TS (MPa)	El (%)	$\bar{r}$	BH (MPa)
Hot-dip galvannealed	208	357	41	1.9	42
Organic composite coated	196	353	42	2.0	39

Sheet thickness: 0.7 mm

This type of sheet has been around for a long time. However, no material has offered high strength (tensile strength of 340 MPa or higher) combined with an ultra deep drawing property (Lankford value (r-value), which shows deep drawability, exceeding 2.0). A cold rolled steel sheet with an r-value of 2.0 or higher and bake hardenability (BH) of approximately 40 MPa can be obtained by applying high temperature annealing at 850°C or higher and rapid cooling at 30°C/s or higher to a steel material with a carbon content of 0.003% or less and a composition in which Nb is added so that the atomic ratio of Nb and C (Nb/C) is approximately 1.0. Kawasaki Steel also mass produces galvannealed steel sheets and organic composite coated steel sheets with properties equivalent of those of cold rolled sheets. **Table 1** shows examples of the mechanical properties of these materials[3].

By strictly controlling the Nb/C ratio, it is also possible to export products that are guaranteed not to age for 6 months.

2.2 590 MPa Class Galvannealed Steel Sheets

With dual phase (DP) steel sheets which contain martensite in the ferrite phase, high strength of 590 MPa or more can easily be obtained while maintaining high ductility. Because these materials have a low yield ratio, they also have excellent shape fixability. Moreover, DP steel also has a larger collision absorbed energy at high strain rates than other steel types with the same strength due to the fine dispersion of the second phase "martensite", and is therefore suitable for crash-resistant parts[4,5]. DP steels have long been supplied for auto parts in the existing product lines of hot rolled and cold rolled steel sheets. However, with galvannealed steel sheets (GA), which are the most widely used anti-corrosion steel sheets in Japan, there are problems with structural control due to the heat cycle of GA, and problems with plating properties due to the composition of the sheet. Thus, with rising need for stronger corrosion resistance worldwide, demand has increased for 590 MPa class hot dip galvanized DP steel sheets.

Table 2 shows a chemical composition of the steel which Kawasaki Steel recently developed for hot dip

Table 2 Chemical compositions of the developed steel

(mass%)

C	Mn	P	S	Al	Mo
0.080	2.00	0.010	0.005	0.042	0.15

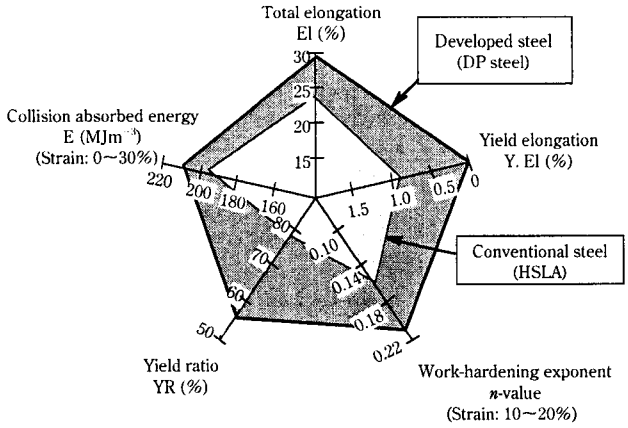

Fig. 2 Mechanical properties of the developed steel

galvanizing. **Figure 2** shows its mechanical properties in comparison with HSLA steel[6]. Even in the GA process, it is possible to obtain a martensite structure, platability is not a problem, and a high total elongation of 30% can be obtained.

2.3 780 MPa Class Hot Rolled Steel Sheets with High Fatigue Strength and Good Formability

Most steel for road wheels used to be high tensile strength hot rolled steel sheets in the class 590 MPa or under. However, demand has risen to use 780 MPa hot rolled steel sheets to reduce weight.

Road wheels are a typical example of a hard-to-form part. At the same time, the steel should have high fatigue strength in notched portions which are opened by piercing and similar work.

Kawasaki Steel developed and is now mass-producing a 780 MPa class hot rolled steel sheet with both good formability and highly fatigue strength by applying Ti precipitation hardening of the ferrite phase, using a multi phase microstructure consist of ferrite and martensite. An example of the chemical composition is shown in **Table 3**; typical mechanical properties are shown in **Table 4**. **Figure 3** shows the relationship between the tensile strength and fatigue limit in case of machined specimens and notched specimens in a plane bending fatigue test[7]. In comparison with the conventional HSLA steel and DP steel, it is clear that the new steel possesses excellent fatigue properties.

3 Steel Sheets for Packaging

Metal containers, such as beverage cans, may be

Table 3 Chemical compositions of newly developed 780 MPa TS grade steel

(mass%)

C	Si	Mn	Ti	P	S	Al
0.08	1.50	1.80	0.10	0.010	0.001	0.030

Table 4 Mechanical properties of newly developed 780 MPa TS grade steel

Thickness (mm)	YS (MPa)	TS (MPa)	El (%)
3.2	653	816	24
4.5	638	832	22
6.0	659	834	22

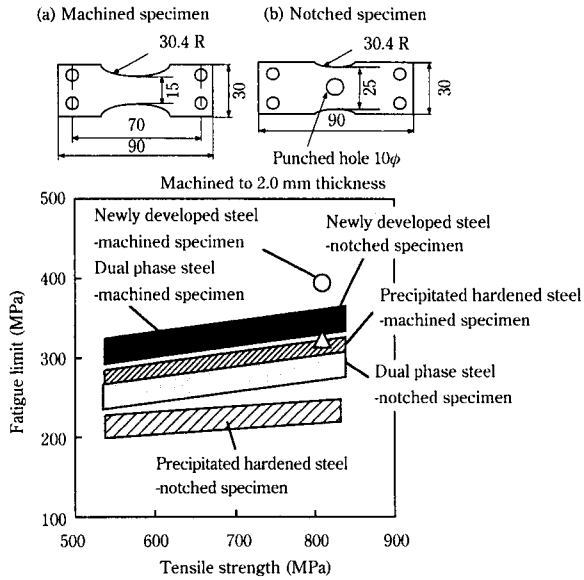

Fig. 3 Effect of microstructure and tensile strength on fatigue limit

broadly classified as 2-piece and 3-piece cans, depending on their structure. Two-piece cans consist of two parts, the can body and can end, which are formed by various press forming methods, and include DI cans (drawn and ironed cans) and drawn & thin redraw cans. Coating and printing are performed after forming. Three-piece cans consists of three parts, the can body and two ends. In this case, the steel sheet is coated and printed in advance, formed into a cylindrical can body, and the parts are joined by welding or cementing.

Total world production of food cans is approximately 80 billion units per year, and is thought to include as many as 1 200 types. Because food cans are used in such large quantities, there are also needs for light weight and to make neck-in forming more efficient. To reduce can weight, it is applicable to use thinner gauge base material. However, the material must possess the mutually contradictory properties of high hardness (to maintain the strength of the can body) and high neck-in formability.

Table 5 Typical mechanical properties of the developed steel

	Steel	Grade	YS (MPa)	TS (MPa)	El (%)	Y. El (%)	r-value
Batch annealing	Low C	T1	225	348	37	0	1.3
Continuous annealing	Ultra-low C	T1	225	348	41	0	1.8

Thickness: 0.25~0.32 mm

Table 6 Typical mechanical properties of the developed steel comparing with conventional steel

Steel	As temper rolled			After aging (at 210°C)		
	YS (MPa)	TS (MPa)	El (%)	YS (MPa)	TS (MPa)	El (%)
Conventional	314	416	25	402	409	27
With 100 ppm N addition	408	454	26	427	445	26

Thickness: 0.18 mm JIS No. 5 specimen (longitudinal direction)
Base steel: 0.04%C-0.2%Mn-0.04%Al

3.1 Ultra Thin Gauge Steel Sheets for Soft Tempered Canning Material

The production of can materials with thickness of the 0.2 mm class, which are called ultra thin gauge steel sheets, now requires the application of the continuous annealing process, as this process offers the advantages of high productivity and uniform material properties.

It is possible to reduce Δr (anisotropy of the r-value), which has an effect on earing during drawing, and simultaneously to suppress aging by adding a trace amount of Nb to an ultra low carbon steel base material.

If approximately 0.5% Mn is also added to ultra low carbon steel with a trace addition of Nb, it is possible to obtain soft tempered steel sheets with highly formability for cans by normal hot rolling, cold rolling, and continuous annealing. **Table 5** shows the typical mechanical properties of this steel sheet[8]. Because the newly developed steel has better ductility than the low carbon box annealed steel which was used in this comparison, excellent punch stress formability can be expected. An excellent deep drawing property can also be expected, as the new steel has a high r-value.

3.2 Ultra Thin Gauge Steel Sheets for Hard Temper Canning Material

Higher hardness materials have been progressively adopted for hard tempered ultra thin gauge steel sheets for 3-piece cans. For example, conventional steel sheets for the body of 190 g beverage cans had been a temper of T4 with thickness of 0.20 mm. Recently, however, a temper of T5 with thickness of 0.18 mm have come into use.

Methods of obtaining high hardness include increasing the content of hardening elements such as C and Mn in the steel and work hardening by secondary cold rolling after annealing. However, increasing the content of C and/or Mn also increases deformation resistance in hot and cold rolling, which makes it difficult to manufacture ultra thin gauge products with this composition. Furthermore, in welded can applications, since the weld heat affected zone is hardened markedly the flange formability is deteriorated. Work hardening by secondary cold rolling has the advantage of reducing the thickness and simultaneously increasing the hardness of the steel sheet. However, the uniform elongation is markedly reduced, and because the yield ratio increases, spring-back also increase.

To solve these problems, a new steel sheet was developed utilizing the strengthening element N, which had seldom been used in the past. This steel sheet has extremely desirable features. For example, the material is soft during forming and is then effectively hardened by rapid strain aging after canmaking. At the same time, it is also possible to avoid canmaking problems such as fluting (folding which occurs during cylindrical forming), which could have occurred due to the addition of N. **Table 6** shows typical mechanical properties in comparison with a conventional steel[9]. After aging treatment equivalent to baking after painting, the new steel shows a large increase in strength as a result of strain aging hardening with solute nitrogen. This steel sheet is widely used to reduce the thickness of the can material while maintaining the same level of can body strength.

4 Steel Sheets for Electrical Appliance

This chapter will discuss steel sheets used in household electrical appliances, including peripheral devices for personal computers and copying machines.

In the past, JIS standard cold rolled steel sheets had been used as material for household electrical appliances. Parts that required corrosion resistance, were plated after press forming (post-plated). With the popularization of home appliances, a more rational production process was developed, resulting in expanded demand for pre-plated steel sheets. Because appliances are used in the home, heavy coating weights are not necessary, and electrogalvanized steel sheets were therefore adopted as the main material. Because zinc rust (white rust) forms on the as-galvanized surface, deteriorating its appearance, trivalent chromium coating (chromate coating) or other chemical conversion treatments were normally applied.

It is normal practice with the internal parts of home appliances to leave the steel surface bare, without painting. Therefore, resistance to fingerprinting is required so that fingerprints will not be noticeable even if the material with bare hands. Steel sheets coated with an organic resin coating over the chromate film are frequently used

Table 7 Performance of "RIVER ZINC FX"

Test item	Test condition	Result		
		RIVER ZINC FX	RIVER ZINC F*	RIVER ZINC C**
Finger print resistance	Discoloration measurement with artificial sweat solution	1.0 under	0.8 under	3.5 under
Corrosion resistance	Salt spray test 5% NaCl at 35°C (JIS Z 2371)	120 h over***	144 h over***	48 h over***
Chemical resistance	Immersion test in gaseous trichloroethylene at 50°C for 4 min	No change	Slightly changed	No change
	Immersion test in gaseous trichloroethylene at 90°C for 4 min	No change	Slightly changed	No change
Conductivity	Electric resistance measurement on the surface	0.1 Ω under	0.5 Ω over	0.1 Ω under

*Finger print resistant steel sheet (resin coated type)
**Conventional chromate treated steel sheet
***Time to generate white rust covered more than 5% of the surface

to obtain this fingerprint resistance. However, if an organic resin film is applied to a steel surface, the steel loses its good electric conductivity, impairing its weldability and groundability. In other words, there are cases when other functions must be sacrificed to give the functions required by the customer. For this reason, it is important to develop products based on the major premise of supplying products that are easy for the consumer to use.

4.1 Highly Corrosion Resistant Chromate Treated Steel Sheets

As mentioned above, fingerprint-resistant steel sheets coated with an organic resin film are frequently used, but because the organic resin film acts an insulator, the electric conductivity of the steel sheet surface is remarkably reduced in comparison with ordinary electrogalvanized steel sheets. Recently, stricter standards have been applied to electromagnetic noise to prevent damage due to electromagnetic waves. As a result, surface conductivity has been adopted as a selective standard for the steel sheets used in home appliances.

The highly corrosion resistant chromate treated steel sheet River Zinc FX maintains a high resistance to corrosion and fingerprinting that is equal to the resistance of organic resin coated type anti-fingerprinting steel sheets, and at the same time, has surface conductivity equal to that of ordinary electrogalvanized steel sheets.

Because reactivity with the substrate Zn plating is suppressed and a stable chromate film is formed by high temperature drying, River Zinc FX has higher resistance to corrosion and fingerprinting than conventional chromate treated materials. **Table 7** shows the performance of River Zinc FX in comparison with the organic resin treated anti-fingerprinting sheet River Zinc F and the conventional chromate treated material River Zinc C[10].

4.2 Self-lubricating Steel Sheets with Good Conductivity

In response to deterioration of the working environment and destruction of the ozone layer by the fluorocarbon solvents used in degreasing after press forming, self-lubricating steel sheets which provide the same level of press formability as conventional products, but without using press oil, have gained wide popularity. However, because these self-lubricating sheets are coated with a film composed mainly of organic resin, the electric resistance of the surface is higher and surface conductivity is lower than conventional materials. The self-lubricating steel sheet River Zinc FE is a self-lubricating sheet with surface conductivity on the same level as conventional sheets.

Figure 4 shows a schematic diagram of the film composition of River Zinc FE, which consists of a coat-type chromate layer containing a polyethylene wax lubricant (particle size of approximately 0.2 μm) over an electrogalvanized steel sheet. Because the particles of polyethylene wax are dispersed in islands, conductable points are secured in the film and surface conductivity is not impaired. **Table 8** shows the performance of River Zinc FE in comparison with the organic resin film type self-lubricating steel sheet River Zinc FS and the above-mentioned River Zinc FX[11]. River Zinc FE has a self-lubricating property equivalent to that of River Zinc FS, and also provides corrosion resistance and conductivity on the same level as River FX.

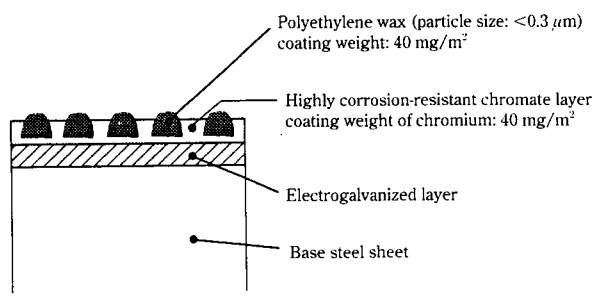

Fig. 4 Schematic diagram of RIVER ZINC FE

Table 8 Comparison of performance of RIVER ZINC FE with those of RIVER ZINC FS and FX

Property	Test item	Result		
		RIVER ZINC FE	RIVER ZINC FS	RIVER ZINC FX
Conductivity	Surface electric resistance	0.2 Ω under	1~100 Ω over	0.1 Ω under
Consecutive spot weldability	Number of spot welding of electrode tip life[a]	3 000 over	150	3 000 over
Lubricant property	Friction coefficient by drawing test	0.15~0.25	0.10	0.35~0.45
Press formability	LDR by cup drawing test[b]	2.09	2.33	1.8 under
Corrosion resistance	Time to the occurrence of 5% white rust area in the 5% NaCl solution spray test at 35°C	120 h over	200 h over	120 h over

[a]Electrode: Cu-Cr, CF (5 mmφ) type
Electrode force: 1 960 N
Welding current and time: 8.5 kA × 10 cycles
Sheet thickness: 1.0 mm

[b]Blank holder force: 19.6 N
Punch diameter: 33 mmφ
Drawing speed: 60 mm/s

4.3 Deep Drawing Quality Hot Rolled Steel Sheets with High Ductility and Anti-secondary Working Embrittlement Property

In the shells of compressors for cooling equipment such as refrigerators and air conditioners, hot rolled steel sheets with high ductility are used. Materials for compressor shells must naturally have high ductility that enables deep drawing, and must also have a high anti-secondary working embrittlement property to maintain component reliability. Secondary working embrittlement occurs when the material which completes the first working receives the impact force, and frequently displays a so-called "longitudinal crack" fracture morphology, in which cracking occurs in a straight line along the forming direction during cylindrical forming.

Following the ban on fluorocarbons as refrigerants due to global environmental problems, large scale compressors and thicker shells have been adopted, requiring more stringent drawing and increased material thickness. Because both requirements are disadvantageous for secondary working embrittlement, hot rolled steel sheets should have an improved anti-secondary working embrittlement property.

The product which Kawasaki Steel developed in response to this need is hot rolled steel sheet with high ductility for deep drawing KFN5, which offers much better ductility and anti-secondary working embrittlement than conventional hot rolled steel sheets due to uniform refinement of the microstructure and refined dispersion of precipitated carbides. These breakthroughs were made by applying the optimum thermo-mechanical treatment to ultra low carbon steel in the hot rolling process. **Tables 9** and **10** show the typical chemical composition and mechanical properties of KFN5 in comparison with those of a conventional steel (SPHE) and Kawasaki Steel's conventional hot rolled steel sheet for deep drawing use, KFN3. **Table 11** shows typical results of the secondary embrittlement test. Brittle cracking occurred in SPHE at −120°C, but did not occur in KFN5 even at −196°C, showing that the newly developed steel has an outstanding anti-secondary working embrittlement property.[12]

Table 9 Chemical compositions of hot-rolled mild sheet steels

(mass%)

	C	Mn	P	S	Others
SPHE	0.04	0.3	0.01	0.01	Al-killed
KFN3	0.002	0.1	0.01	0.003	Ti, B added
KFN5 (Newly developed)	0.002	0.1	0.01	0.003	Ti, B added

Table 10 Mechanical properties of hot-rolled mild sheet steels

	Thickness (mm)	YS (MPa)	TS (MPa)	El (%)	Average r-value
SPHE	4.5	225	335	48	0.8
KFN3	4.5	185	285	56	0.9
KFN5 (Newly developed)	4.5	203	295	56	0.9

Table 11 Results of secondary embrittlement test

	Testing temperature (°C)						
	−100	−120	−130	−140	−150	−180	−196
SPHE		××					
KFN3		○○	○×	××			
KFN5 (Newly developed)	○○	○○	○○	○○	○○	○○	○○

○ : Ductile × : Brittle

5 Conclusion

Adopting a "market-in" standpoint and having an

accurate grasping of customers' needs at all times has enabled Kawasaki Steel to supply steel sheets with new and advanced functions in a more economical and timely manner for the customer.

As the most important matter of world concern in the future, concerted efforts must be made to preserve of the global environment. Technical development is required to ensure the coexistence of human and nature. For this purpose, Kawasaki Steel must continue to work with customers to develop environmentally-friendly steel sheet products.

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