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Steel Sheets for Can-making†

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Abstract:

JFE Steel has been providing various types of latest steel sheets for cans. UNIVERSAL BRITE is one of the resin-film laminated steel sheets for food cans, 18 ℓ cans and pail cans and is applicable to conventional uses, in the place of lacquered material sheets, where cans are formed by drawing and seam-welding using lacquered tin free steels (TFS). Because resin film applied does not contain any harmful substances such as organic solvents, its safety for foods has been completely assured. Recently, requirements for diverse can shape designs have been increasing. It is very hard to manufacture so-called fancy cans, like candy- or chocolate-cans, of numerous designs secured through vigorous forming processes and to which, ultra low carbon steel sheets having high formability are applied.

1. Introduction

The principle of manufacturing canned foods was invented by a Frenchman named Nicolas Appert (1750–1841), and tinned beef produced by this method was among the stores of food taken in Admiral Perry's polar expedition in 1824. When one of the same cans was opened 114 years later, the content was still in satisfactory condition,[1)] demonstrating that tin cans have excellent long-term food preservation properties. Thereafter, tin cans continued to earn an enviable reputation as safe and reliable food containers.

In more recent years, advanced tinplate manufacturing processes such as continuous cold rolling and electrolytic tinplating, and ultra-thin tinplated steel sheets with excellent seam weldability were developed. With the appearance of tin free steel (TFS) as a tinplate substitute with excellent paint adhesion, TFS gained wide acceptance and is used today in both cemented cans and welded cans in the beverage can and 18 *l* can fields. Accompanying the development of stretched-and-drawn cans (TULC), TFS laminated with thermoplastic resin which is suited to this process was developed and put into mass production.[2)]

The development of these steel sheets for can-making, beginning with tinplate, was a result of the pursuit of economy in aspects, including high speed can-making, high speed filling, thinner materials for weight reduction, and resource saving, as well as the long-term stable preservation properties of beverage and food cans. Thanks to outstanding technical development to meet diverse needs, steel sheets now occupy a principal position among canning materials. In particular, steady progress has been made in reducing sheet thickness, including improvements in processing technology and can shape, and the thickness of 2-piece can material has now reached 0.18 mm, achieving a light weight of 25 g (inner capacity: 350 g, positive pressure can). On the other hand, with rising social awareness of the environment, recent years have also seen increasing demand for manufacturing technologies which minimize waste and do not use harmful substances in order to reduce environmental risk, and for low CO_2 emission over the entire can life cycle. Steel is also an outstanding material from this viewpoint. For example, in 2002, the recycling ratio of steel cans was 86.1%, making an significant social contribution in environmental terms.

As part of this history of development, this report describes recent steel sheets for can-making supplied by

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2. Food and Beverage Cans

2.1 New Laminated Steel Sheet for Food Cans "UNIVERSAL BRITE Type F"

Lacquered steel sheets have long been used in the canned food industry. However, because the bis-phenol contained in lacquer is an endocrine disrupter, the EU is moving to regulate this material, highlighting the need for a new type of laminated steel sheet. As basic requirements, the new sheet should have properties equal or superior to those of the conventional lacquered sheets (formability, adhesion, corrosion resistance, release property) without using endocrine disrupters, and should be applicable with existing equipment.

JFE Steel therefore developed and applied the world's first new laminated steel sheet for food cans which satisfies these requirements for food cans, beginning with the meat release property, and can also be manufactured at low cost. The development concept is shown in **Fig. 1**.

The structure of the new laminated TFS sheet for food cans is shown in **Fig. 2**. The substrate for the laminated film is TFS produced by electrolytic precipitation of metallic chromium and chromium hydroxides on a cold-rolled steel sheet. A newly developed 2-layer PET (polyethylene terephthalate) film is laminated on this steel sheet by heat sealing.

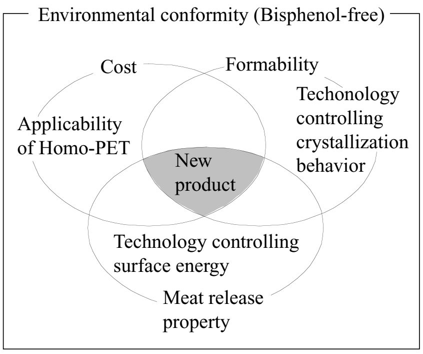

Fig. 1 Development concept

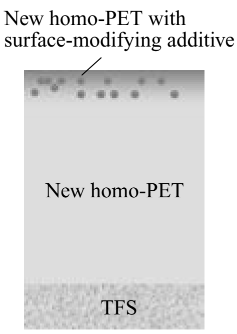

Fig. 2 Cross-section of the laminated TFS for food cans

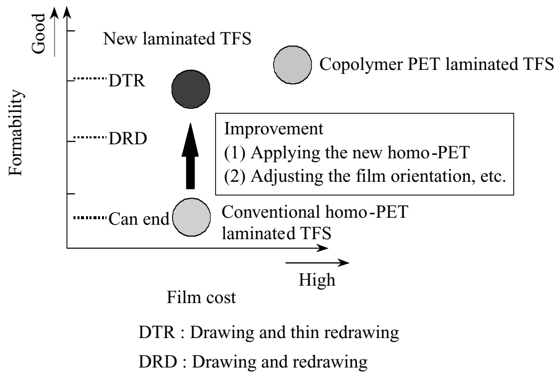

Fig. 3 Formability of the new film laminated TFS

From the viewpoint of cost, an inexpensive homo-PET film is used as the base layer of the 2-layer film. Since the crystallization rate of conventional homo-PET is extremely fast (approximately 10 times faster than copolymer PET), however, rapid crystal growth occurs during the can-making process, reducing formability. For this reason, the conventional homo-PET cannot be used without improvement.

To solve this problem, JFE Steel adopted a new homo-PET film, in which the crystallization rate is reduced by a special molecular structure design, as the base layer film. The results of an investigation of formability when this film is laminated on TFS are shown in **Fig. 3**. Formability was greatly improved by adjusting the degree of film orientation after lamination, realizing a new process for food cans (DRD: drawing and redrawing). Moreover, further improvement in formability can be achieved by optimizing the film layer structure after lamination.

To improve the meat release property, a newly improved type of homo-PET film was adopted for the upper layer of the 2-layer film. The release property shows a correlation with the surface free energy of the material in contact with the can content, improving as the energy value decreases. The results of an evaluation of the release property with sample materials having different surface energies are shown in **Fig. 4** and **Table 1**.

As shown in Fig. 4, conventional PET laminated steel sheets have high surface energy, resulting in an inferior release property. As a means of reducing the surface energy of PET laminated steel sheets, JFE Steel studied the addition of surface-modifying additives to the film, with the results shown in **Fig. 5**. Although effectiveness differs depending on the type of additive, additive C was found to be the most effective. An improved release property was realized by adding the proper amount of this additive to the new homo-PET film. However, addition to the film as a whole could cause separation of the PET film and TFS substrate. Therefore, addition was limited to the upper PET layer, preventing any negative effect on adhesion between the laminated film and TFS

Table 1 Evaluation method for meat release property

Score	3	2	1	Before taking contents out
Meat release property	The contents are easily taken out with hardly any content left sticking to the cup	The contents are rather difficult to be taken out with part of the contents left sticking to the cup	The contents are difficult to be taken out with much of the contents left sticking to the cup	(1) Contents: Mixture of meat, egg, and oatmeal (2) Retort condition: 121ºC×90min
Appearance after the contents were taken out				

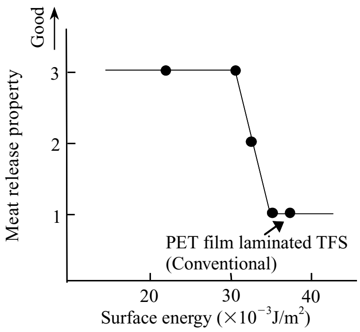

Fig. 4 Effect of surface energy on meat release property

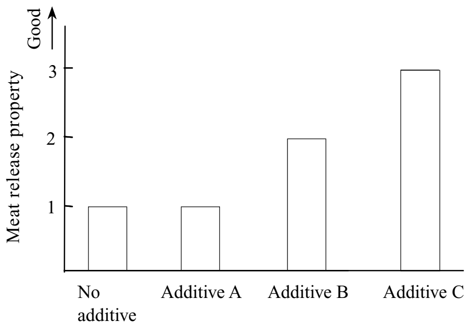

Fig. 5 Effects of various surface-modifying additives on meat release property

1/2 pound can   1 pound can

Photo 1 Cans made from the new film laminated TFS

while also minimizing production costs.

Photo 1 shows examples of actual can-making using JFE Steel's new laminated steel sheet for food cans. The can types are of two classes, 1/2 pound and 1 pound. The cans are free of rupture, cracks, and wrinkles, confirming that the new sheet has satisfactory can-making properties. A test of change over time showed that cans also maintain satisfactory properties after the contents are packed.

In summary, JFE Steel has successfully developed and commercialized a new laminated steel sheet for food cans called UNIVERSAL BRITE Type F (food) which contains no endocrine disrupters and possesses an excellent release property and formability. This sheet is now in mass production for foreign markets, centering on North America. As a "next-generation standard product" steel sheet for food cans, substantial growth in sales of UNIVERSAL BRITE Type F is expected in the future.

3. 18 *l* Cans and Pail Cans

3.1 Laminated Steel Sheet for 18 *l* Cans and Pail Cans "UNIVERSAL BRITE Type E"

As pointed out in recent years, the inside lacquer materials used in cans contain formaldehyde and other toxic chemical substances. From this viewpoint, large can makers, including manufacturers of 18 *l* cans, have shown an increasing tendency to switch to environment-friendly laminated cans. Use of laminated steel sheets resin-coated at the steel works also makes it possible to omit the inside lacquer-coating process conventionally performed by the can maker, and thus is advantageous from the viewpoint of can-making costs. JFE Steel therefore developed and commercialized the world's first coil laminated steel sheet for 18 *l* cans, called UNIVERSAL BRITE Type E (ecology), which can be filled with a wide range of contents at a low cost in comparison with lacquered cans.[3)]

UNIVERSAL BRITE Type E for general applications has a PP (polypropylene) film coating which is chemically stable in the presence of a wide range of substances from acidic solutions to alkaline solutions, while Type E for food applications uses a PET film which does

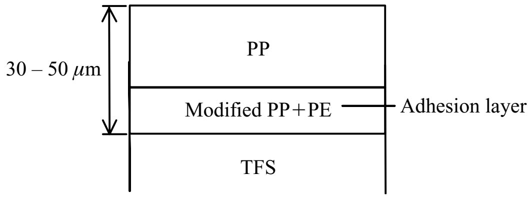

Fig. 6 Cross section of PP laminated steel sheet for 18 *l* can

not affect the flavor of the can content. Thus, these new sheets can be used with a diverse range of contents, corresponding to the needs of the can-making user.

The structure of the PP laminated steel sheet for general applications is shown in **Fig. 6**. As with Type F, the substrate steel is TFS produced by electrolytic precipitation of metallic Cr and Cr hydroxides on cold-rolled steel. However, with Type E, a newly devised 2-layer PP film is laminated on the TFS material by heat sealing.

From the viewpoint of heat resistance, high melting point (160°C) PP is used on the surface layer side of the 2-layer film to prevent film melting due to the heat of the baking process when content markings, etc. are printed on the outside of the can.

By nature, PP resin has a poor adhesive property. Therefore, an adhesion layer is necessary to bond the PP film and TFS substrate. In this adhesion layer, a proper amount of modified PE (polyethylene) is mixed with PP to impart an adhesive property by carboxylic acid modification. Addition of PE increases interfacial adhesion with the TFS sheet because the wettability during heat sealing is improved. Conversely, however, excessive addition increases the difference in the compositions of the PP + PE adhesion layer and the surface PP layer, reducing the bonding force between the 2 resin layers.

Figure 7 shows the influence of the PE ratio in the adhesion layer on (a) cross-cut corrosion resistance and (b) film adhesion (peeling) strength. Cross-cut corrosion resistance was evaluated by immersing a laminated steel sheet on which cross-cutting had been performed in an alkaline solution with a high delamination property for 2 weeks at high temperature, and then measuring the film delamination width. Film adhesion strength was evaluated by pasting together test pieces cut to a 5 mm width with the PP film side as the inner side, then peeling the film by the T peel method and measuring the peeling strength.

As the PE ratio in the adhesion layer increases, the bonding force at the film-TFS interface also increases, preventing penetration by the alkaline solution from the cross-cut edges and thereby reducing interfacial peeling. On the other hand, higher PE ratios also increase the composition difference between the 2 resin layers, reducing the interlayer bonding force and film peeling strength. In particular, insufficient peeling strength has

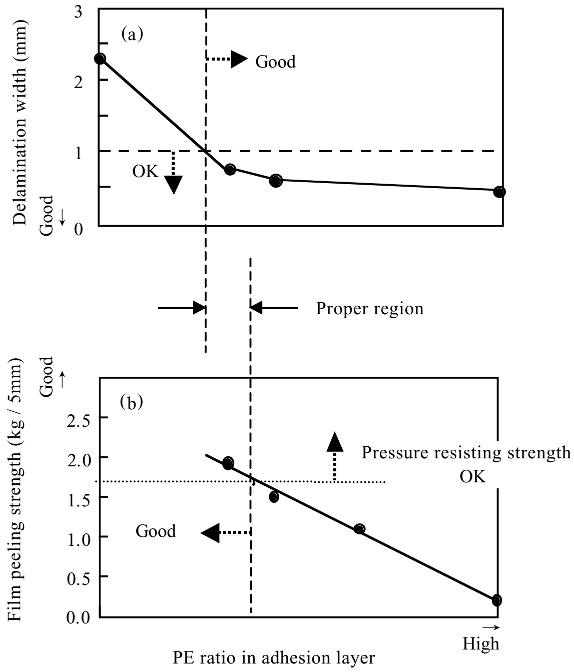

Fig. 7 Influence of PE ratio in adhesion layer on (a) cross-cut part corrosion resistance and (b) film adhesion strengh

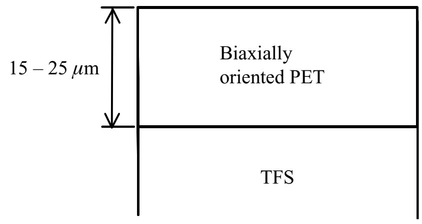

Fig. 8 PET laminated steel sheet for 18 *l* can

various negative effects, for example, causing susceptibility to peeling at the can lid seam and reducing pressure resisting strength to an inadequate level.

As can be understood from Fig. 7, the PE ratio has a proper region where cross-cut corrosion resistance and film adhesion strength requirements are both satisfied. JFE Steel sets the adhesion layer PE ratio in this region, realizing both high corrosion resistance and good film adhesion.

Figure 8 shows the structure of the Type E PET laminated steel sheet for food applications. A biaxially oriented PET film copolymerized with isophthalic acid is laminated on the TFS, and both formability and film strength are obtained by properly controlling the quantity of oriented crystals in the film. This film has high corrosion resistance against food components such as organic acids and sulfides and is therefore satisfactory for food applications.

Photo 2 shows an example of an actual can made of UNIVERSAL BRITE Type E. It should be noted that this is an 18 *l* welded can made of a laminated steel sheet with the PP film laminated on the grinding-free TFS sheet for welded cans, JFE BRITE, discussed in

Photo 2 An example of 18 *l* welded can made of UNIVERSAL BRITE type E

the following section. In addition to excellent corrosion resistance with general contents from acidic solutions to alkaline solutions, it also possess high pressure resisting strength, satisfying the standards of the Hazardous Materials Safety Techniques Association, and has received an outstanding evaluation from can-makers.

3.2 Grinding-free TFS for Welded Cans

Steel cans are frequently used as containers such as 18 *l* cans and pail cans. As the can-making method, the can body is joined using the copper wire as an electrode.

Materials for steel cans are broadly divided into tinplate and TFS. Tin free steel is a type of coated steel in which an extremely thin film of metallic Cr and Cr hydroxides is formed on a steel sheet and has a thickness of less than 1/10 that of tinplate. Because tin is not used, TFS possesses excellent lacquer adhesion and corrosion resistance after lacquer coating, and is also widely used as a material with superior recyclability.

However, because the Cr hydroxides which form the upper film layer on the TFS sheet have extremely low electrical conductivity, local overheating will occur in areas where the welding current passes if welding is performed without removing the film. As a result, the defect called expulsion and surface flash tends to occur more easily, making stable welding impossible. A grinding process to remove the plated film is therefore necessary before welding. However, removal of the film causes various problems, including poor lacquer adhesion and reduced corrosion resistance in the ground area and contamination of the can surface by grinding dust. For these reasons, a welded can which enables stable welding without film grinding was strongly desired.

JFE Steel developed JFE BRITE to meet these requirements and JFE CLEAN to enable seaming without wax. These materials are used in the market for 18 *l* cans and pail cans.

3.2.1 Grinding-free TFS "JFE BRITE"

The properties required in TFS include good welding performance without grinding and satisfactory corrosion resistance. The TFS film comprises a metallic Cr layer on a steel substrate and a Cr hydroxide layer on the metallic Cr. To satisfy welding performance requirements, it is necessary to reduce the Cr hydroxide layer and make the layer homogeneous. On the other hand, to secure corrosion resistance, the film must cover the material completely and uniformly.

Based on a study of the plating bath and strip path for reducing the Cr hydroxide layer and securing uniform coating, JFE Steel succeeded in forming the thin, uniform Cr hydroxide layer shown in **Photo 3**. The company also succeeded in forming a uniform metallic Cr layer by adopting a special process.[4, 5)]

The mash seam welding method using a narrow lap width and the wide-lap welding method using a wide lap width (commonly called "butterfly" seam welding) are used in welding 18 *l* cans and pail cans. Although these methods are widely applied with TFS when the Cr layer is removed by grinding, stable welding performance cannot be obtained with conventional materials without grinding. In contrast, stable welding performance can be obtained with JFE BRITE simply by making slight adjustments in the existing welder. The weld structures obtained in a welding test at an actual line are shown in **Photo 4**. Because JFE BRITE has a thin, uniform Cr hydroxide layer, a satisfactory weld structure is formed without expulsion, enabling grinding-free welding. With conventional TFS, molten drops of steel caused by expulsion were observed, and the external appearance of the weld was inferior.

The covering property of the Cr film with JFE BRITE is shown in **Fig. 9**, using the results of a $CuSO_4$ dipping test. The $CuSO_4$ test is a test method in which

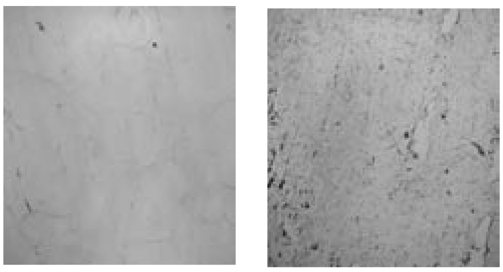

Photo 3 Electron transmission micrographs of Cr hydroxide layers (JFE BRITE vs. Conventional TFS)

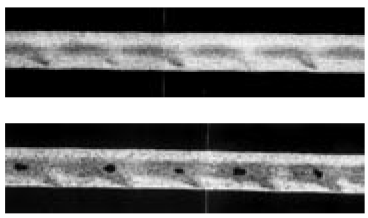

Photo 4 Longitudinal sections of the welds

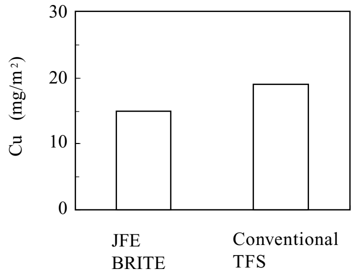

Fig. 9 Cu extraction obtained by the $CuSO_4$ dipping test

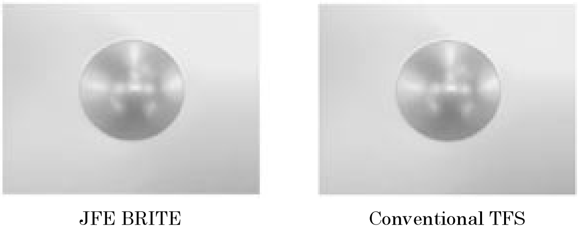

Photo 5 Results of humidity cabinet test (Temperature : 30°C, Humidity : 70–80%, 3d)

the amount of exposed steel is evaluated by precipitating out Fe by substitution with Cu. Smaller precipitation values indicate that the steel is more perfectly covered. The Cr film with JFE BRITE has a value similar to that of conventional TFS, showing that the new product has an excellent covering property. **Photo 5** shows the results of an uncoated corrosion test after Erichsen cup drawing, and indicate that the JFE BRITE film has high uncoated corrosion resistance, equal or superior to that of conventional TFS.

JFE BRITE is not only widely used in manufacturing 18 *l* cans and pail cans as a type of TFS which enables grinding-free welding, but as mentioned in Sec. 3.1, is now also frequently used as an environment-friendly laminated steel sheet (clean material + omission of lacquer coating process) in these markets.

3.2.2 Grinding-free TFS "JFE CLEAN"

The film composition of JFE CLEAN is shown in **Fig. 10**. The film composition of the surface is based on JFE WELT, which has high weldability. Although the material is plated with tin to secure weldability and the sliding property, the tin coating weight is minimized to approximate the appearance and corrosion resistance of TFS as closely as possible, while the Cr coating weight (metallic Cr, Cr hydroxides) is increased to secure lacquer adhesion and resistance to the can contents (resistance to alkaline solutions).

(1) Weldability

An evaluation of film weldability without grinding using a welder for 18 *l* cans confirmed that an adequate available current range (ACR) can be secured (**Fig. 11**).

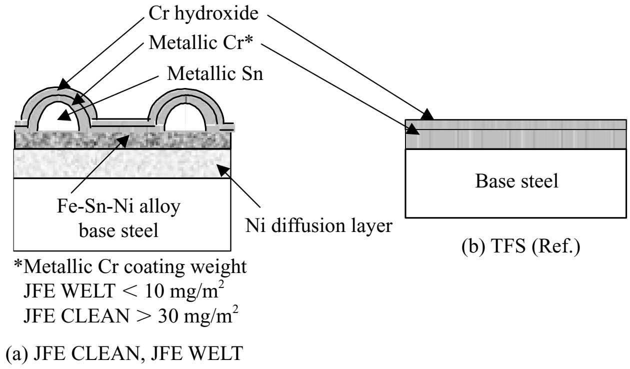

Fig. 10 Schematic cross-sectional views of JFE CLEAN, JFE WELT and TFS

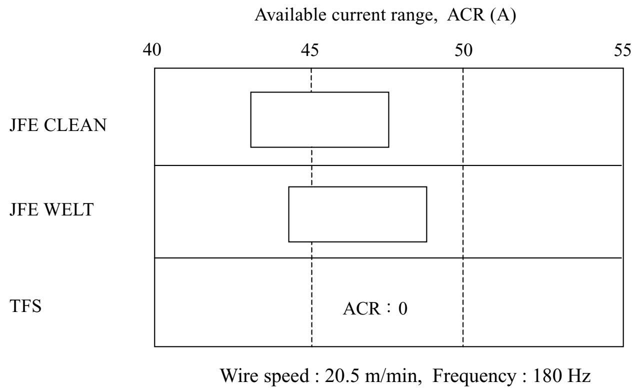

Fig. 11 Weldability of JFE CLEAN in comparison with JFE WELT and TFS

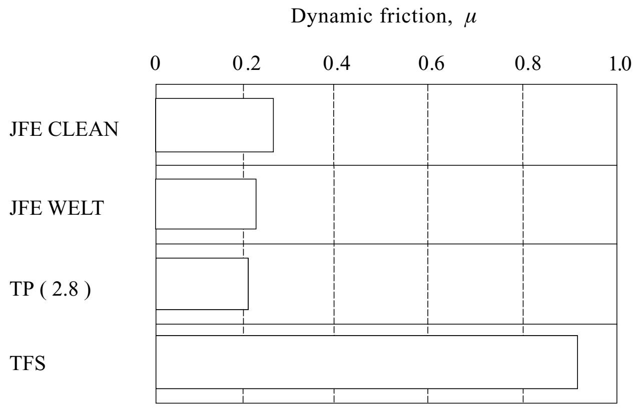

Fig. 12 Surface friction of JFE CLEAN in comparison with JFE WELT, tinplate (TP) and TFS

(2) Sliding Property

Measurements of the dynamic friction coefficient of the steel sheet surface (**Fig. 12**) showed that JFE CLEAN has a satisfactory sliding property, approximately equal to that of tinplate with 2.8 g/m^2 coating weight.

(3) Resistance to Corrosion by Can Contents

Discoloration occurs in some cases when a strong alkaline solution is applied without lacquer. However, with other contents and inside lacquer specifications, corrosion resistance equivalent to that of TFS was confirmed (**Table 2**).

Table 2 Examples of corrosion resistance test

	Lacquer (Inside)				Without lacquer	
	Water paint	Detergent	Soy sauce	NaOH	Ethyl alcohol	Recycled thinner
JFE CLEAN	○	○	○	△	○	○
TFS	○	○	○	○ – △	○	○

○ : Good, △ : Fair 50°C×1 month

4. General Cans (Fancy Cans)

As illustrated in **Photo 6**, fancy cans are products which have the functions of toys or decorative objects as well as the basic function of containers, and are produced in diverse shapes and external finishes. These cans have enjoyed increasing demand in recent years, particularly in products for recreational facilities such as amusement parks. The following describes the material design of TFS as a material for fancy cans.

Among the distinctive features of fancy cans, an attractive shape, including a smooth curved surface with a streamlined or curved form, is required. Accordingly, the material must satisfy the property requirements shown in **Table 3**. In particular, the most important property is formability, which must be adequate for extremely difficult forming applications. As can be seen in **Table 4**, forming difficulty of fancy cans is actually higher than that of automobile gasoline tanks and DI beverage cans, which are representative examples of products with a high degree of forming difficulty.

Photo 6 Fancy cans

The following describes the mechanical property design of materials for fancy cans with the properties mentioned above, considering the gondola-shaped can in Photo 6 (lower right) as an example. Because the forming process for the gondola can in this photo is a type of complex forming involving deep drawing with stretch forming, wall cracks (bend breakage) can easily occur during press-forming at parts with a small radius of curvature. As shown in **Table 5**, total elongation and the *r*-value have a large influence on composite forming by deep drawing with stretch forming. Specifically, stretch forming is improved by increasing elongation, while the deep drawing property is improved by increasing the *r*-value.

Initially, batch annealed steel sheets of a low carbon base steel with temper grade: T2 were applied in fancy cans, but to meet severe forming requirements, steel makers switched over to continuous annealed sheets of ultra-low carbon base steel. Nevertheless, with more difficult forming requirements, such as the gondola can, cracks occurred when the elongation value of the material fell below 38% or the *r*-value was less than 1.5. **Table 6** shows the actual average values of elongation and the *r*-value by material specification (temper grade). Bend breakage was prevented by applying an ultra-low carbon continuous annealed (T1CAL) material as the material for hard-to-form fancy cans, including the gondola can.

Table 3 Required properties for fancy can

Property	Effective factor
Formability	Mechanical properties, Roughness
No oil canning	Thickness
Beauty	Roughness, Appearance of material
Multi-layer paintability	Shape of material

Table 4 Influence of mechanical properties on difficult forming

Usage	Influence of mechanical property						Degree of forming	Difficulty of forming
	YP	TS	El	*r*-value	*Δr*	*n*-value		
Gas tank	○	—	○	◎	—	△	Low	Middle
DI can	—	○	△	◎	◎	—	Middle	Middle
Gondola can	—	○	◎	◎	—	○	High	High

◎ ○ △
High ←→ Low
Influence

Table 5 Influence of mechanical properties on formability

Forming trouble	Mechanical properties					Thickness
	YP	TS	T-El	*n*-value	*r*-value	
α-breakage (Deep drawing)	—	—	—	○	◎	○
α-breakage (Stretch forming)	—	△	◎	○	△	○
Bend breakage	—	△	○	△	—	◎

◎ High ◄— ○ Influence —► △ Low

Table 6 Average values of elongation and *r*-value

Temper grade	Elongation(%)	*r*-value
T1CAL	42	1.69
T2CAL	41	1.66
T1BAF	40	1.52
T2BAF	38	1.49

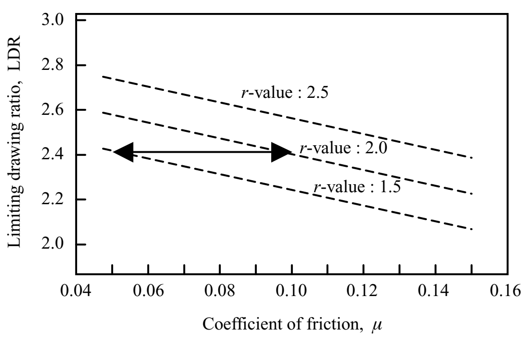

Fig. 13 Relationship between coefficient and limiting drawing ratio (LDR)

Ultra-low carbon continuous annealed steel sheets are used in T1 and T2 temper grade materials, giving *r*-values and elongation higher than those of conventional low carbon batch annealed sheets, and are therefore better suited to difficult forming.

It is possible that new cans with even harder-to-form shapes will appear in the future, but because there are limits to improvement in formability by material properties alone, new approaches from angles will be necessary. In addition to material properties, reduction of frictional resistance is also effective in preventing rupture during drawing. As shown in **Fig. 13**, reducing the friction coefficient by 0.05 has an effect equivalent to reducing the *r*-value by 0.5. Thus, processing which requires higher *r*-values can be performed successfully if frictional resistance is reduced by modifying the roughness or wax specification. For new types of fancy cans, as with other products, JFE Steel applies advanced research technologies to determine the required material properties, for example, using analytical software which enables simulation of the forming process.

In the future, appropriate material design will be performed by developing and applying these technologies to new hard-to-form cans in order to supply materials with minimal breakage or other forming trouble during press-forming. JFE Steel also intends to apply materials which are not included in the conventional category of "steel sheets for can-making" and carry out joint research with press product manufacturers.

5. Conclusions

This report has described representative steel sheets for can-making commercialized by JFE Steel in recent years. In addition to further improvement in the safety and reliability achieved in steel cans to date, innovation in container materials to meet social needs is also necessary. As a conclusion to this paper, this section discusses future development trends in steel sheets for can-making.

Where steel materials are concerned, potential thickness reductions must be realized. Because aluminum and plastic have smaller specific gravities than steel, future containers made from these competitive materials will be lighter in weight than steel. The high strength of steel is essential in supporting high speed can-making and filling, but it is also necessary to develop steel sheets with higher strength to maximize these benefits and achieve further reductions in thickness. Although large problems relating to the manufacturing process, such as improvement in cold rolling efficiency and expansion of the applicable manufacturing range of the continuous annealing process, must be solved in order to reduce material thickness and realize higher strength, continuing improvement in can-making technology is also necessary.

In recent years, the materials and shapes of containers have become increasingly diverse. Restrictions have been eased in all stages from container manufacturing through sales by progress in packing technologies such as sterile (pasteurized) packing and nitrogen gas packing techniques, shortening of the life cycle of beverage cans, and improvements in the refrigerated storage and distribution infrastructure. As it has become possible to package beverages in any type of container desired, combinations of beverages and containers have also diversified. Resealability and visibility of the content have been pointed out as desirable container functions, but elements which affect the sensory feel of the product, such as warmth when held and a sense of familiarity, also appear to be important. Thus, as an essential element for the future development of steel cans, it must be possible to provide the functions demanded by users in steel containers, while continuing to maintain the outstanding properties of steel cans.

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