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Development and Performance Properties of New Coated Steels for Welded Cans

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Abstract:

Welded cans are the mainstream of such non-pressurized beverage cans as coffee and tea cans. They are made of tinplate and nickel-coated steel to some extent, but mostly of lightly tin-coated steel (LTS) with a coating weight of 1.5 g/m^2 *or less. LTS is available in two major types: tin-nickel plate and nickel-free LTS, the latter being aimed at stabilizing the overall can quality encompassing high-speed weldability, corrosion resistance, and lacquer-coated appearance. Both LTS grades are produced on the basis of uniform light tin coating technology. Control of tin melting on the tinning line, control of tin alloying reaction during lacquer baking in the canmaking process, and improvement in corrosion resistance by electrolytic chromate treatment are key to the production of the LTS grades. This paper describes considerations in the property control of the two LTS grades, and the results of their overall property evaluation.*

1. Introduction

Japan's canned food and beverage production has been increasing in the past several years. Non-carbonated beverages, including coffee, tea and lactic acid beverages, have been remarkably increasing since 1986. Canned beer is also gaining proportion in the total beer production with growing beer consumption. The total beverage can production reached about 31.6 billion cans in 1992. By type of can, drawn and wall ironed (DWI) cans markedly increased. Aluminum and steel DWI cans rose 9% and 1% respectively over the preceding year1). Welded three-piece cans continue to grow, supported by a stable increase in canned coffee consumption. Steel can production has increased as noted above, but steel consumption for canmaking purposes has hovered at about 1.6 million tons because of downgauging in the past few years.

By type of material, low-cost welded can materials such as tin-nickel plate (lightly tin-coated steel (LTS) with its tin coating preplated by nickel or nickel-preplated LTS) have come into wide usage in place of tinplate. **Table 1** compares the properties of welded can materials in widespread use in Japan. Tinplate is excellent in weldability and corrosion resistance and is stably available, but is costly. Nickel plate costs less and offers excellent

Table 1 Characteristics of welded can materials

Item		Tinplate (#25ET)	Nickel plate	Tin-Nickel plate
Quality	Weldability	Ex	F～G	G
	Corrosion resistance	Ex	F～G	G
	Lacquer adhesion	F	Ex	G
Cost		P	G	G
Productivity		G	F	F

Note Ex: Excellent, G: Good, F: Fair, P: Poor

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lacquer adhesion, but has only fair weldability and corrosion resistance.

Tin-nickel plate is low in cost and superior in quality. It has thus become a principal welded can material at Japan's leading canmakers in the past several years. Because of its low coating weight, however, tin-nickel plate delicately differs from mill to mill in surface profile and coating composition. The resultant problems pointed out by canmakers include large variations in finishing color tone appearance and the need for frequent adjustment of welding conditions.

To meet the demand from canmakers for materials that are more uniform in quality, Nippon Steel started work on the development of optimum materials for welded cans and succeeded in commercializing nickel-free lightly tin-coated steel (LTS) in 1991.

This report mainly describes Nippon Steel's technology development concerning tin-nickel plate and nickel-free LTS. Concerning the former, detailed discussion is made on the manufacturing technology centering on alloying control. Discussion about the latter deals with the alloying control technology and product properties, including comparison with the former in terms of product quality.

2. Experimental Methods

2.1 Materials

Experimental materials were produced on a commercial tinning line (Ferrostan bath). The strip was pretreated and preplated with nickel as necessary before tinning. The LTS substrate was 0.22-mm thick aluminum-killed continuously-cast steel with the temper T-4CA. When the reflow treatment was employed, the tin-iron alloy coating weight ranged from 0.15 to 0.70 g/m^2. The LTS was given the electrolytic chromic acid treatment employed in the manufacture of tin-free steel (TFS). For the purpose of comparison, the cathodic dichromate treatment adopted in conventional tinplate production was also applied.

2.2 Analytical methods

The nickel coating weight and total tin coating weight were determined by the X-ray fluorescence method, and the free tin coating weight was determined by the electrolytic stripping method specified in JIS G 3303. The tin-iron alloy coating weight was calculated from the total tin coating weight and free tin coating weight. The chromium oxide (Cr^{ox}) and electrochemically determinable chromium (Cr^{EC}) in the chromium film was measured by the X-ray fluorescence method. $Cr^{ox} = A - B$ and $Cr^{EC} = B - C$, where A = total chromium content in the as-received condition, B = chromium content after 5-s immersion in a hot alkaline solution (7.5N-NaOH at 95°C), and C = chromium content when the specimen after the determination of B is anodically electrolyzed in a weakly alkaline phosphoric acid solution.

2.3 Welding test

The available current range (ACR) was obtained from the results of welding experiment with a laboratory seam welding machine of capacity comparable to that of a commercial seam welding machine. The welding conditions were the welding speed of 53 m/min, current frequency of 400 Hz, electrode force of 45 kgf, and lap of 0.4 mm. The lower and upper limits of the ACR were evaluated by testing the specimens for bond strength with a tear ring (45°) and by visually inspecting the specimens for expulsion. The specimens were baked at 205°C for 20 min before the welding test.

Contact resistance that is strongly correlated to weldability was also measured. The specimens were baked and stamped into 57-mm diameter circular disks. Two disks were lapped, held between 4-mm diameter spot welding copper tip electrodes under a force of 50 kgf, and supplied with 2-A current. The contact resistance was calculated by measuring the voltage between the disks and between the electrode tips.

2.4 Lacquer adhesion test

In the lacquerability evaluation tests, the specimens were coated with an epoxy phenol lacquer to 50 mg/dm^2 and baked at 200°C for 20 min. Flat-area lacquer adhesion was evaluated by cementing the lacquered specimens with nylon and testing the cemented joint for T-peel strength. Deformed-area lacquer adhesion was evaluated by drawing the lacquered specimen into a square 5A can, boiling the can in 0.5% citric acid for 60 min as necessary, and peeling the lacquer film at the can corners with tape.

2.5 Filiform corrosion resistance test

The lacquered specimen was crosscut with a knife, stretched into a 3-mm high Erichsen cup, salt spray tested for 1 h, held at 37°C and 80% relative humidity for 1 week, and evaluated as to filiform corrosion.

2.6 Sulfide staining resistance

The lacquered specimen was stretched into a 5-mm high Erichsen cup, repacked with oiled tuna in a test can, retorted at 115°C for 90 min, opened, and evaluated as to sulfide staining on the surface.

2.7 Undercutting film corrosion resistance

The lacquered specimen was scribed with an X mark using a knife, stretched into a 15-mm high Erichsen cup, used as an end to hot pack an undercutting film corrosion (UCC) solution (composed of 1.5% sodium chloride and 1.5% citric acid and adjusted to pH 3), left to stand at 70°C for 20 h, and tested for the amount of iron dissolved from the steel substrate (iron solution value). At the same time, the lacquer film of the Erichsen cup was peeled with tape, and the area of the lacquer film peeling was determined by an image analyzer.

2.8 As-printed appearance

The bare specimen was coated with a golden-color can printing ink to a dry coating weight of 5 g/m^2 and baked at 155°C for 10 min. The printing machine was an Akira Seisakusho Model RI-1 rotary ink tester. The color of the printed specimen was measured with a Shimadzu Model UV-2100 automatic recording spectrophotometer. The results were represented by the Hunter color specification system, and the L value in diffuse reflection was examined.

3. Experimental Results and Discussion

3.1 Alloying control of tin-nickel plate

The lacquer film is repeatedly baked at relatively low temperatures of 160 to 210°C in the can lacquering and printing stages. This baking operation forms a large amount of tin-iron alloy in the tinplate. The resultant decrease in the free tin coating weight adversely affects weldability as well as corrosion resistance and appearance.

To improve its corrosion resistance and weldability, the tin-iron alloy formation behavior in this temperature region of tin-nickel plate was determined, and how to control the tin alloying reaction was studied[2)].

3.1.1 Effect of nickel coating weight

Fig. 1 shows the tin-iron alloy formation of non-reflowed LTS specimens during oven baking. Since the nickel-tin alloy is formed on the nickel flash coated surface at room temperature, the alloyed tin coating weight before baking increases in proportion to the nickel coating weight. The alloyed tin coating weight of the non-electrolytic chromic acid-treated specimen, when baked, moves generally in parallel by an amount attributable to the heating. The electrolytic chromic acid treatment accelerates the increase of the alloyed tin coating weight. This effect is particularly noticeable with non-nickel flash-coated specimens and is alleviated by the nickel flash coating. When the specimen is electrolytic chromic acid treated, the alloyed tin coating weight after baking becomes the lowest near a nickel coating weight of 5 mg/m^2.

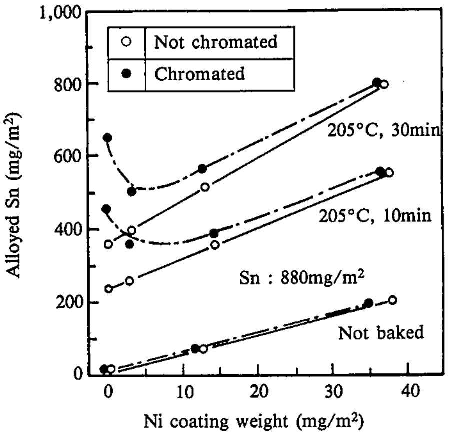
This effect of tin coating weight is also recognized with reflowed specimens. **Fig. 2** shows the relationship between the increment during baking of alloyed tin coating weight of reflowed specimens after the electrolytic chromic acid treatment and the alloyed tin coating weight of as reflowed specimens. When the specimen is reflowed, the increment of alloyed tin coating weight due to the baking decreases with increasing nickel coating weight, reaches a minimum near the nickel coating weight of 15 mg/m^2, and increases again thereafter.

3.1.2 Effect of electrolytic chromic acid treatment

As shown in **Fig. 3**, the increment of alloyed tin coating weight linearly increases with increasing amount of not Cr^{ox} (chromium oxide) but Cr^{EC} (electrochemically determined chromium) in the chromium film formed by the electrolytic chromic acid treatment. The effect of Cr^{EC} is reduced by the nickel flash coating and is made negligibly small by the reflow treatment.

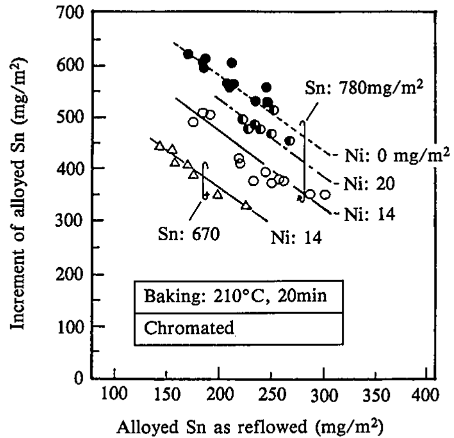
3.1.3 Effect of alloy formed during reflow treatment

The alloyed tin coating weight after baking is the sum of alloyed tin formed during reflowing and that formed during baking. The position of the flow line was changed in the reflowing section of the electrolytic tinning line (ETL), and the amount of alloyed tin formed during reflowing was investigated for its effect on the amount of alloyed tin formed after baking. The results are shown in **Fig. 4**. To reduce the alloyed tin coating weight after baking, the alloyed tin coating weight should be controlled at 400 mg/m^2 or less during the reflow treatment.



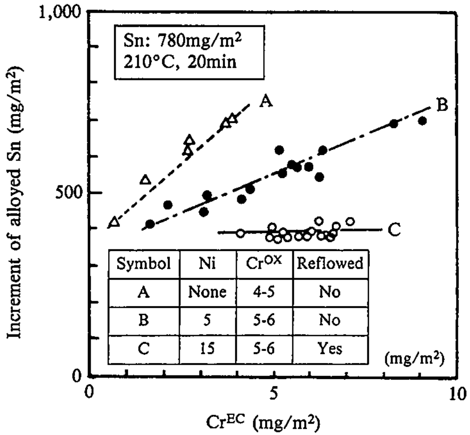
Chromated: Cr^{EC} : 4 mg/m^2, Cr^{OX} : 6 mg/m^2

Fig. 1 Tin alloying behavior of non-reflowed LTS during baking



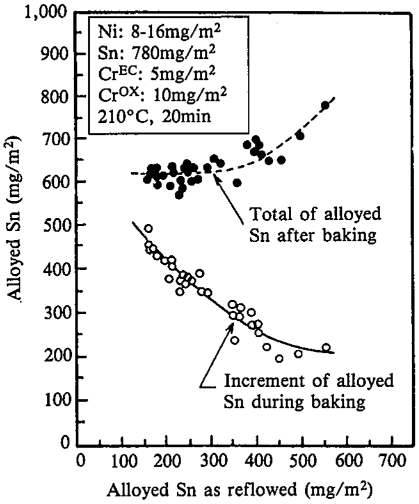
Chromated: Cr^{EC} : 5 mg/m^2, Cr^{OX} : 10 mg/m^2

Fig. 2 Tin alloying behavior of reflowed LTS during lacquer baking



Reflowed: Alloyed Sn as reflowed 250 mg/m^2

Fig. 3 Effect of Cr^{EC} on tin alloying behavior



Line speed: 240m/min, Flow line level from the water surface: 0.5-4m

Fig. 4 Effect of reflowed tin-iron alloy coating weight on tin-iron alloy layer growth during baking (line experiment)

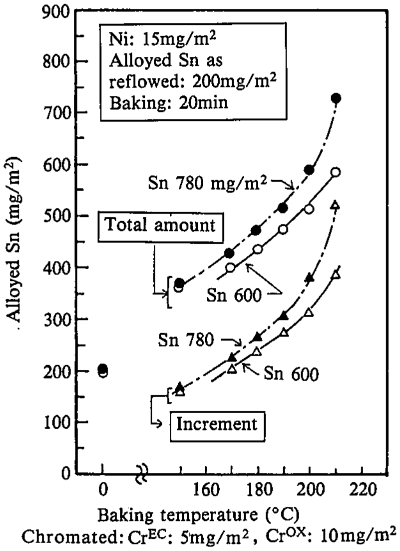


Fig. 5 Effect of tin coating weight on tin-iron alloy layer growth

The alloyed tin initially formed in a trace amount by nickel preplating controls the orientation of the tin-iron ($FeSn_2$) alloy formed during baking and strongly orients the high-atomic density $FeSn_2$ (002) plane parallel to the steel sheet surface, thereby inhibiting the growth of the alloy during reflowing and baking. Furthermore, the change in this preferred orientation plane has the effect of retarding the dissolution reaction of metallic tin in a corrosive environment and improving underfilm corrosion[3].

Fig. 5 shows the effect of the tin coating weight on the growth of the tin-iron alloy layer when the amount of alloyed tin during reflowing is held constant. The amount of alloyed tin after baking is influenced by the tin coating weight and decreases with decreasing tin coating weight.

3.2 Coating design of tin-nickel plate

As discussed above, tin-nickel plate is produced by applying a nickel flash coating of about 15 mg/m² or less to the steel substrate, lightly coating the steel with tin, and reflowing the tin coating to a tin-iron alloy coating weight of 400 mg/m² or less. Although detailed data are not presented here, tin-nickel plate has satisfactory service performance properties, such as weldability and corrosion resistance. Its coating composition is shown in **Fig. 6**.

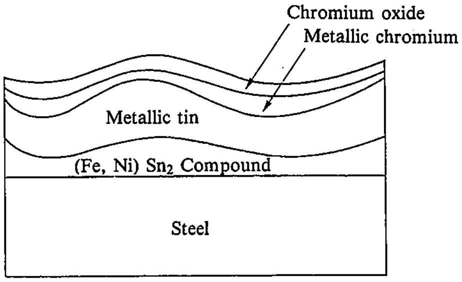


Fig. 6 Schematic illustration of cross section through tin-nickel plate

3.3 Quality control of nickel-free LTS

Described next is the quality design of the nickel-free lightly tin-coated steel (LTS) for welded cans with smaller quality variations and superior weldability and corrosion resistance.

3.3.1 Weldability

Free tin, that is not alloyed with iron on the steel surface, has a good effect on seam weldability[4]. **Fig. 7** shows the effect of the free tin coating weight on seam weldability. The available current range (ACR) expands with increasing free tin coating weight. When chromated to a chromium weight of 5 mg/m², the nickel-free LTS has a wider ACR. The chromium coating weight in the range of 20 to 30 mg/m² has a smaller effect on the ACR. To obtain an ACR comparable to that of tin-nickel plate in commercial use, the free tin weight after baking must be 0.5 g/m² or more.

Fig. 8 shows the effect of static contact resistance on the ACR.

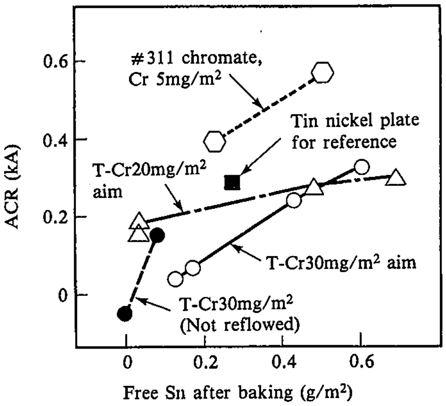
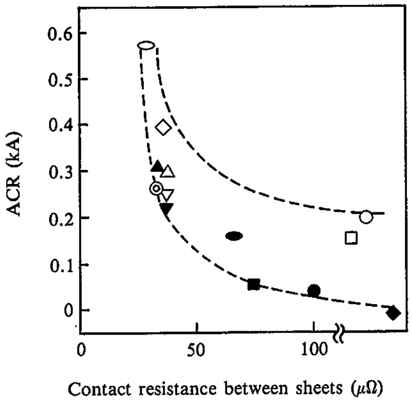


Fig. 7 Effect of free tin weight on ACR (after baking at 205°C for 20 min)



	No.	Total Sn coating weight (g/m²)	Reflowed	Cr coating weight (mg/m²)
—○—	1	0.8	Yes	20
---□---	2	1.0	Yes	20
---▽---	3	1.3	Yes	20
—△—	4	1.5	Yes	20
—●—	5	0.8	Yes	30
···■···	6	1.0	Yes	30
---▼---	7	1.3	Yes	30
-·-▲-·-	8	1.5	Yes	30
—◆—	9	0.8	No	30
---⬬---	10	1.0	No	30
—◇—	11	1.0	Yes	5 (#311)
---⬭---	12	1.5	Yes	5 (#311)
—◎—	Tin-nickel plate			

Fig. 8 Effect of sheet-to-sheet contact resistance on ACR (after baking at 200°C for 20 min)

Although dynamic contact resistance is a more rational variable to be discussed in connection with weldability, the values of static contact resistance are helpful as primary judgment data because they are easy to measure and are fully correlated with the ACR according to past data. The figure shows that the contact resistance must be about 30 μΩ or less to obtain an ACR equal to or better than that of tin-nickel plate. The effect of the free tin coating weight on the sheet-to-sheet contact resistance is shown in **Fig. 9**. From this figure, it is also judged necessary to provide a free tin coating weight of 0.5 g/m^2 or more after baking when the total tin coating weight and the total chromium coating weight range from 0.8 to 1.5 g/m^2 and from 20 to 30 mg/m^2, respectively.

The development of nickel-free LTS has its aim in minimizing the total tin coating weight. To ensure the free tin coating weight of 0.5 g/m^2 or more after baking, it is also necessary to minimize the amount of alloyed tin formed during baking. **Fig. 10** shows the alloying behavior of tin during baking. When the specimen has no initial alloyed tin or is not reflowed, about 0.9 g/m^2 of alloyed tin is formed during the baking. When the specimen is reflowed, only about 0.3 g/m^2 of alloyed tin is formed during baking. When the initial alloyed tin coating weight is 0.5 g/m^2, for example, the alloyed tin coating weight after baking is 0.8 g/m^2 and smaller than that of the not reflowed specimen. To obtain good weldability, it is more advantageous to form an appropriate amount of initial alloyed tin by the reflow treatment.

Fig. 11 (with the same legend as used in **Fig. 8**) shows the effect of the baking temperature on the residual free tin coating weight of specimens with different total tin coating weights and different total chromium coating weights in the chromium film. When the specimen is not reflowed, the free tin coating weight is drastically reduced by baking. The higher the baking temperature in the range of 180 to 210°C, the lower becomes the free tin coating weight. The difference of free tin coating weight between the specimen baked at 180°C and the one baked at 210°C is about 0.1 to 0.2 g/m^2. When the specimen has a total tin coating weight of 1.3 g/m^2 or more and a chromium coating weight of 20 mg/m^2, it has a free tin coating weight of 0.5 g/m^2 or more after baking and is expected to provide good weldability.

3.3.2 Lacquer adhesion

Fig. 12 shows the effect of Cr^{EC} on lacquer adhesion. Lacquer adhesion steeply improves with increasing Cr^{EC} in the Cr^{EC} range of 0 to 10 mg/m^2 and levels off when the Cr^{EC} range is from 10 to 20 mg/m^2. Cr^{EC} is about 5 mg/m^2 for commercial tin-nickel plate and 10 mg/m^2 for nickel-free LTS. This means that the latter has better lacquer adhesion. The improvement in lacquer adhesion with the increase of Cr^{EC} may be explained by the inhibition of tin oxide formation with low cohesive failure strength by the increased amount of Cr^{EC}5).

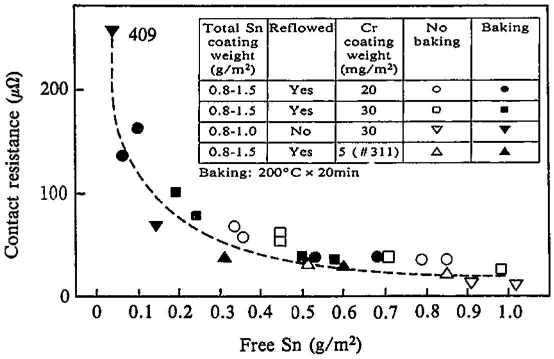


Fig. 9 Effect of free tin weight on sheet-to-sheet contact resistance (after baking at 200°C for 20 min)

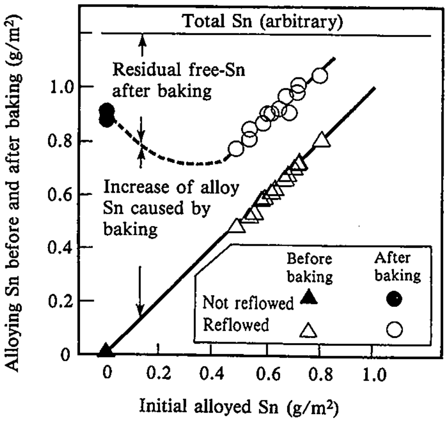
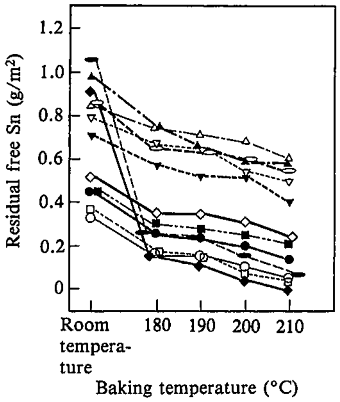


Fig. 10 Effect of initial tin-iron alloy coating weight on loss of free tin during baking at 210°C for 20 min



	No.	Total Sn (g/m²)	Reflowed	T-Cr (mg/m²)
—○—	1	0.8	Yes	20
----□----	2	1.0	Yes	20
----▽----	3	1.3	Yes	20
—·—△—·—	4	1.5	Yes	20
—●—	5	0.8	Yes	30
—··■··—	6	1.0	Yes	30
----▼----	7	1.3	Yes	30
—·—▲—·—	8	1.5	Yes	30
—◆—	9	0.8	No	30
----●----	10	1.0	No	30
—◇—	11	1.0	Yes	#311
----⬭----	12	1.5	Yes	#311

Fig. 11 Effect of baking temperature (for 20 min) on free tin weight

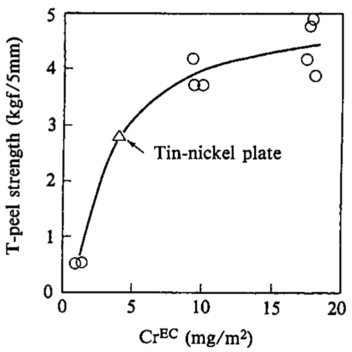
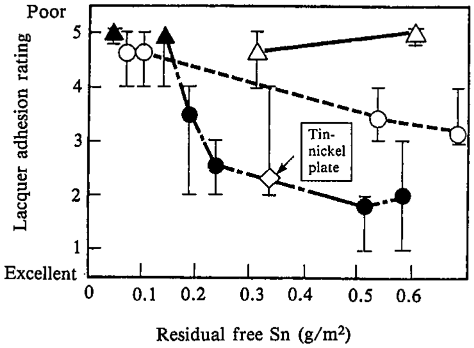


Fig. 12 Effect of Cr^{EC} on lacquer adhesion



	No.	Total Sn (g/m²)	Reflowed	T-Cr (mg/m²)
○	1	0.8	Yes	20
	2	1.0	Yes	20
	3	1.3	Yes	20
↓	4	1.5	Yes	20
●	5	0.8	Yes	30
	6	1.0	Yes	30
	7	1.3	Yes	30
↓	8	1.5	Yes	30
▲	9	0.8	No	30
↓	10	1.0	No	30
△	11	1.0	Yes	#311
↓	12	1.5	Yes	#311

Fig. 13 Effect of free tin weight on primary deformed-area lacquer adhesion

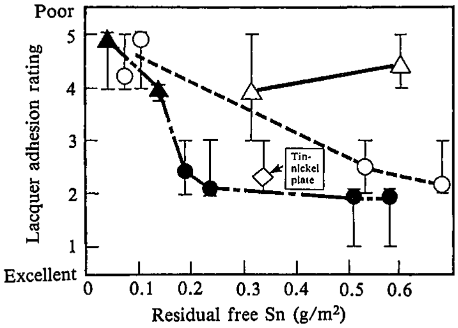


Fig. 14 Effect of free tin weight on secondary deformed-area lacquer adhesion

Fig. 13 shows the effect of free tin coating weight on primary deformed-area lacquer adhesion. When the free tin coating weight is 0.2 g/m^2 or less, lacquer adhesion is poor, irrespective of the level of Cr^{EC}. When the free tin coating weight is 0.3 g/m^2 or more, lacquer adhesion tends to improve, and in that region, the chromium coating weight has a pronounced effect. In other words, lacquer adhesion increases with increasing chromium coating weight. The increased chromium coating weight is considered to improve the lacquer adhesion by inhibiting the formation of tin oxides as supposed for the T-peel strength.

Fig. 14 (with the same legend as used in **Fig. 13**) shows the effect of free tin coating weight on secondary deformed-area lacquer adhesion. A tendency similar to that observed for primary adhesion is recognized.

3.3.3 Filiform corrosion resistance

In Japan, most of the beverage cans and food cans are lacquered and printed on the outside surface. External filiform corrosion resistance is thus one of the important performance properties. **Fig. 15** shows the effect of free tin coating weight on filiform corrosion resistance. Filiform corrosion resistance exhibits such a very interesting tendency that it is good when the free tin weight is 0 or 0.5 g/m^2 or above and is poor when the free tin weight is 0.1 to 0.3 g/m^2. The detailed analysis and discussion of this phenomenon are presented in another report$^{6)}$ and omitted here. The filiform corrosion resistance of nickel-free LTS is greatly influenced by the microscopic distribution of free tin. When free tin is not present at all or is present in such a large amount to completely cover the alloy layer, filiform corrosion resistance is good. When free tin is present in a trace amount and nonuniformly covers the alloy layer, electrolytic micro-cells are formed between the free tin and alloy layers to accelerate filiform corrosion. Nickel-free LTS has good filiform corrosion resistance because it contains 0.5 g/m^2 or more of free tin to ensure good weldability.

3.3.4 Sulfide staining resistance

When nickel-free LTS is used to make cans for packing fish, sulfide stain resistance is an important requirement. **Fig. 16** shows the correlation of sulfide stain resistance with the free tin weight and chromium coating weight. The free tin weight has no effect on sulfide stain resistance. Sulfide stain resistance is better when the chromium coating weight is 20 to 30 mg/m^2 than when it is 5 mg/m^2. Tin-free steel-chromium type (TFS-CT) is known to have good sulfide stain resistance. This characteristic is also found in nickel-free LTS in which chromium is deposited to 20 mg/m^2 or more.

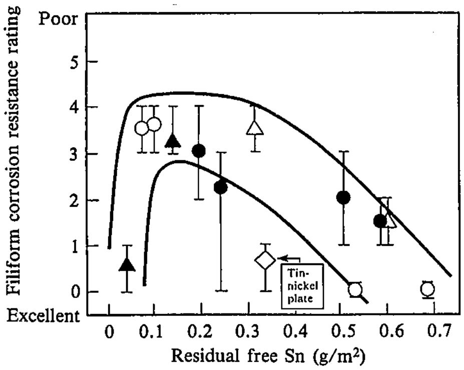


Fig. 15 Effect of free tin weight on filiform corrosion resistance

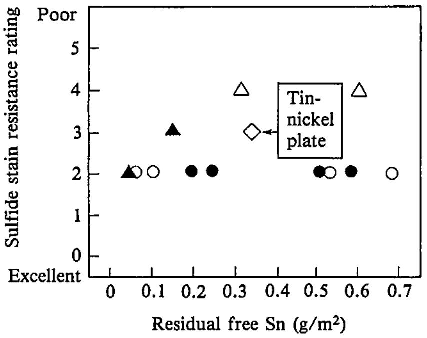


Fig. 16 Effect of free tin weight on sulfide stain resistance

3.3.5 Undercutting film corrosion (UCC) resistance

Nickel-free LTS is used mostly for beverage cans in Japan. The resistance of beverage cans to their contents is usually evaluated in terms of undercutting film corrosion (UCC) resistance. **Fig. 17** (with the same legend as used in **Fig. 13**) shows the effect of the free tin coating weight on the UCC resistance of nickel-free LTS as evaluated by the iron solution value. The free tin coating weight has no or little impact on the UCC resistance of nickel-free LTS. The chromium coating weight has no effect, either. Since its UCC resistance is comparable to that of commercial tin-nickel plate, nickel-free LTS can be used without any practical UCC problems.

Fig. 18 (with the same legend as used in **Fig. 13**) shows the effect of the free tin coating weight on the UCC resistance of nickel-free LTS as evaluated by the peeled area of the lacquer film. As shown in **Fig. 17**, the free tin coating weight and the

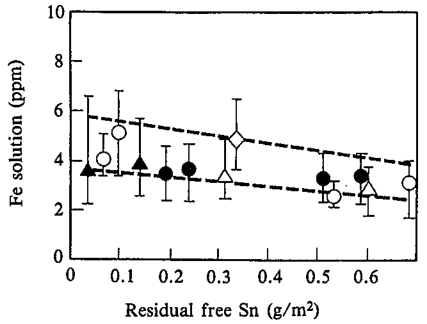


Fig. 17 Effect of free tin weight on UCC resistance (iron solution value)

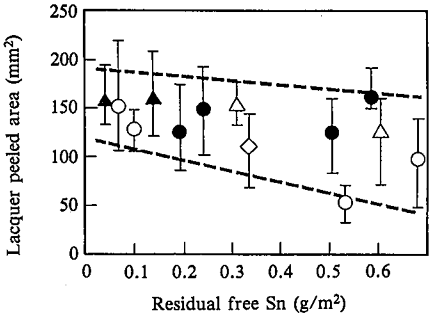


Fig. 18 Effect of free tin weight on UCC resistance (peeled lacquer film area)

chromium coating weight have no or little effect on the UCC resistance of nickel-free LTS.

3.3.6 Appearance after printing

Recently, metallic printing in which the white base coat is eliminated has come to be applied as a popular outside printing method. Steel sheet surface characteristics influence the appearance in general and the brightness in particular of printed sheets. The brightness of printed sheets is generally represented by the Lab values of the Hunter color specification system. The greater the L value, the higher is the brightness of the printed sheet.

Fig. 19 shows the L value after printing of nickel-free LTS reflowed by changing the steel substrate surface profile and free tin coating weight. Scanning electron micrographs of specimen surfaces are given in **Photo 1**. The L value decreases with increasing free tin coating weight on the whole. This may be explained by the increasing weight of molten free tin that reduces the effects of steel substrate surface roughness and minute surface roughness due to tin-iron alloy crystals and inhibits the diffuse reflection of visible light. The L value decreases as the base steel substrate surface smoothness increases in the order of A, B, and C. This may be also explained by the diffuse reflection that decreases as the substrate surface roughness decreases. Nickel-free LTS specimen C exhibits no or little effect of the free tin coating weight. This is probably because the substrate is already so smooth that the smoothing effect of reflowed tin is saturated.

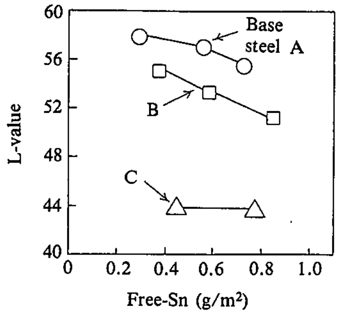


Fig. 19 Effects of free tin weight and minute surface profile on L value after printing

3.3.7 Pack test results

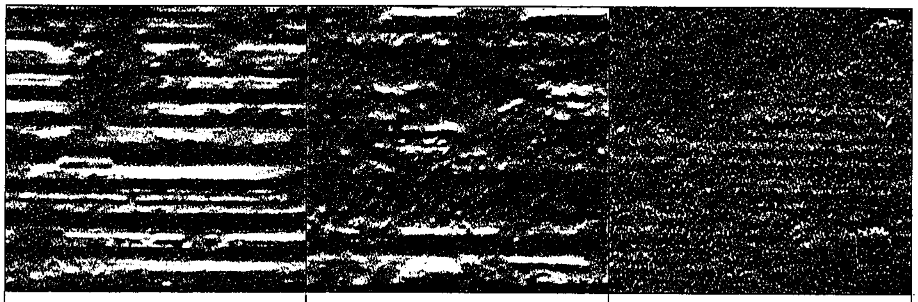
Since nickel-free LTS performed satisfactorily in property evaluation tests as described above, it was then pack tested. Tin-nickel plate and nickel-free LTS cans were double coated with epoxy-phenol lacquer, packed with Oolong tea, black tea (without sugar) and milk tea, stored at 55°C for 1 month, and examined for side seam and body wall corrosion. Neither the tin-nickel plate nor the LTS cans exhibited any abnormality.

3.4 Attempts to produce welded can stock at lower cost

Steel fiercely competes with aluminum, PET (polyethylene terephthalate), and other materials for containers, not limited to welded cans. The steel cost must be minimized to the extent of satisfying its property requirements. Nippon Steel has expended efforts for developing truly TFS-CT, including granular chromium-coated TFS-CT[7], as low-cost welded can materials. These TFS-CT materials as well as those reported by other steelmakers[8,9] do not have commercial high-speed weldability comparable to that of LTS, however.

Nippon Steel also developed stripe tin-coated TFS[10,11], a new type of TFS that has the sideseam weld margin coated with tin to a weight comparable to that of #25 electrolytic tinplate and has the rest entirely composed of TFS. This material for welded beverage cans excels in high-speed weldability and corrosion resistance, but is not yet in commercial application.

Nippon Steel developed another LTS-base material with an



A. Scratched (strong) | B. Scratched (weak) | C. Smooth

Photo 1 SEM images of LTS specimen surfaces (⟵ 20μm)

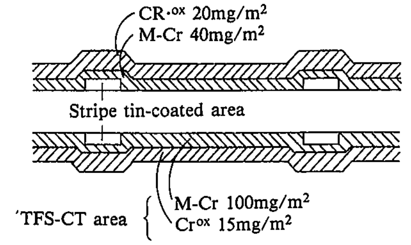


Fig. 20 Schematic illustration of cross section through stripe tin-coated TFS

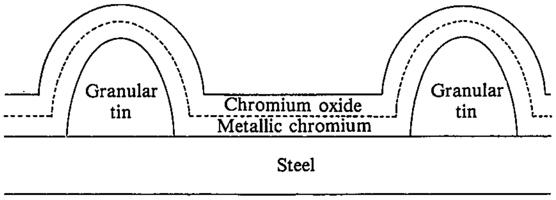


Fig. 21 Schematic illustration of cross section through granular tin-preplated lightly chromium-coated steel

upper layer of light chromium coating and a lower layer of granular tin as a material for general line cans[12]. The trace granular tin coating acts as current path at the start of high-speed seam welding, and there is no welding splash, a shortcoming for TFS. The granular tin-preplated lightly chromium-coated steel is commercially used for general line cans.

The coating compositions of the two new welded can materials are shown in **Figs. 20** and **21**, respectively.

4. Conclusions

Fig. 22 shows the optimum LTS coating composition. Cr^{EC} is necessary for securing good lacquer adhesion and sulfide stain resistance, but it suffices at 10 mg/m². To obtain good weldability, the free tin coating weight must be 0.5 g/m² after baking or must be 0.8 g/m² initially.

Commercial tin-nickel plate has free tin distributed as islands. To obtain this type of free tin distribution, the electrotinning line is limited in production speed and productivity. The nickel-free LTS introduced here features a simple coating composition and manufacturing technology, but calls for special considerations as described below.

First, the tin coating must be uniformly distributed to secure stable quality, weldability, in particular. This can be achieved by using an insoluble anode[13].

Second, Cr^{EC} and Cr^{ox} must be controlled. Unless the bath composition is appropriate, Cr^{EC} does not deposit or Cr^{ox} deposits excessively. It is also important to optimize the current density.

Minute substrate surface roughness also affects appearance, brightness in particular, after printing, and must be controlled over a certain range. The smoother the minute surface profile, the smaller the diffuse reflection and the darker the appearance of printed cans. The minute surface roughness of steel for cans mainly depends on the surface profile of work rolls for temper rolling and is greatly affected by the wear of work rolls. The wear control of work rolls is therefore important.

Lastly, the characteristics of nickel-free LTS as welded can material may be summarized as follows. Nickel-free LTS is superior or equal to tin-nickel plate in weldability, corrosion resistance after lacquering, and lacquer adhesion. Needless to say, the color tone variation in lacquer coating has been remarkably improved of late. The productivity of nickel-free LTS has been significantly raised by reducing the bath changing time and the coated surface contamination.

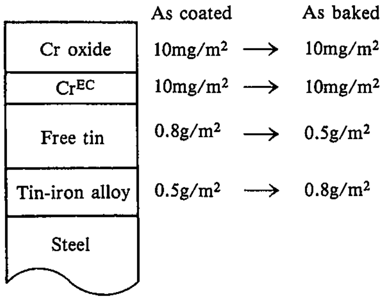


Fig. 22 Schematic illustration of cross section through nickel-free LTS

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