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The body can be viewed from the next page.

Ultra-Thin-Gage and High-Strength Tin Mill Blackplates with Low Planar Anisotropy in *r*-Value for Two-Piece Cans*

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1 Introduction

Can containers are classified into the three-piece and two-piece types according to their construction. Three-piece cans are containers comprising three parts for the can body: the bottom and top ends which are joined by various methods (soldering, cementing and welding) to the roll-formed cylindrical mid-section body made from can steel sheet such as tinplate and tin-free steel (chromium-plated tin-free steel (TFS) to JIS G3315)[1]. Two-piece cans are containers comprising the two parts of can body and bottom end press-formed into one piece, and the top end.[2-4] Two-piece cans are further divided according to the press-forming method into shallow-drawn (SD) cans, drawn and redrawn (DRD) cans, drawn and thin redrawn (DTR) cans,[5,6] and drawn and wall-ironed (DWI) cans.

Two-piece cans have the following advantages over three-piece cans:[4]

(1) The amount of steel sheet used is less.
(2) The weight reduction of the can is easy.
(3) Efficent and continuous production from the steel sheet to the can is possible.
(4) Seaming with the top end is easy because the can body has no joints.

The consumption of two-piece cans has expanded due to these advantages. With national income increasing and vending machines coming into wider use, the

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demand for cans has grown substantially and production has also expanded remarkably.[7)]

Against this background, techniques for weight saving have been positively developed,[8-10)] in addition to improving the basic performance of can containers for the preservation of foods. Examples of these techniques are a reduction in the wall thickness of the can body, which is a principal part of the can,[4,11)] and the use of necking to reduce the diameter of the top end.[12)]

Steel sheets for cans are divided into the following three types according to the manufacturing method and mechanical properties, and are used according to appropriate applications:

(1) Non-aging soft-temper tin mill black plate (TMBP) of low-carbon aluminum-killed steel with outstanding deep drawability that are batch-annealed after cold rolling
(2) Hard-temper TMBP of low-carbon aluminum-killed steel with the strain-aging property that are continuously annealed after cold rolling
(3) Ultra-thin-gage and high-strength double cold-reduced TMBP[13)] of low-carbon aluminum-killed steel that are continuously annealed after cold rolling and then subjected to a second cold rolling at a reduction of several tens percent to reduce the thickness and, at the same time, to obtain work hardening

Double cold-reduced TMBP have also been used in DRD cans that are formed by redrawing to reduce the wall thickness. When double cold reduction is conducted, however, the cup height after press forming becomes uneven, that is, earing becomes greater, and it was necessary to improve this point. Furthermore, in reducing the wall thickness of DWI cans that are formed by deep drawing and wall-ironing, it was necessary to obtain greater resistance of the bottom end to withstand the internal pressure of the carbon dioxide contained in beverages, and to increase the column strength to prevent breakage of the can during transport.[14)] Consequently strength was increased by improving the shape of the bottom end by using high-strength steel sheets. However, earing became still greater when these measures were taken. Furthermore, when applied to long beverage cans, materials that are soft during forming, possess high formability, and become hard by the succeeding heat treatment were desired.

As already mentioned, can-making methods have been improved to reduce the wall thickness, so that ultra-thin TMBP that provide the necesaary can strength and possess high press formability were desired.

In this paper, DRD cans that meet the requirements shown in **Table 1** and that can be produced from double cold-reduced TFS, and DWI cans that also meet the same requirement and that can be produced from single cold reduced tinplate are studied as typical two-piece cans. The development of ultra-thin gage and high-strength tin mill blackplate is also described.

Table 1 Usage and required materials for DRD and DWI cans

	DRD cans		DWI cans	
	Conventional	Light-weight	Conventional	Light-weight
Usage	Tuna cans Pet food cans		Beverage cans	
Can-manufacturing methods	Drawn & redrawn		Drawn & wall ironed	
Plating methods	Chromium plated tin free steel		Matte finish tinplate with an unmelted tin coating	
Required materials				
Temper grade	T4	DR8	T1	T4
Rockwell hardnes T scale (HR30T)	61	73	49	61
Proof stress (MPa)	340	550	250	340
Tickness (mm)	0.21	0.17~0.20	0.30	0.24
$\bar{r}$ value	≧1.1	≧1.1	≧1.3	≧1.3
Δr	0 (aim)	0 (aim)	0 (aim)	0 (aim)

2 Development of Ultra-Thin-Gage and High-Strength Tin Mill Blackplates for DRD Cans

DRD cans are of the two-piece type, so that the vacuum condition can be easily maintained by the can's high resistance to the difference between internal and external pressures. Therefore, DRD cans are suitable for applications in which vacuum seaming and a retort treatment are conducted after filling with food, and are used as short cans for tuna and pet food.

Hard-temper TFS with the strain-aging property in a thickness of 0.21 mm and with the T4 temper grade in accordance with JIS G3315 (Rockwell T-scale hardness (HR30T) of 61 and proof stress of 340 MPa) has been used in the past. The progress in can-making techniques has resulted in double cold-reduced products now being used of ultra-thin-gage and high-strength TFS that has a thickness between 0.17 and 0.20 mm and DR8 (HR30T 73 and proof stress of 550 MPa). With the DRD method, TFS possessing outstanding lacquer adhesion is lacquered beforehand, and the cans are continuously formed by utilizing the lubricating effect of the lacquer film.[3)] Therefore, steel sheets with a high r-value, which is the index of deep drawability, are required for DRD cans so that cupping can be performed at the minimum frequency of drawing. However, the bending stiffness decreases with decreasing gage and wrinkles are prone to be formed during drawing. Furthermore, when the blank-holding force is increased to suppress wrinkling, the material is apt to break and, therefore, the required can height is achieved not by a single deep drawing operation, but by subsequent redrawing. As a result, the required average r-value ($\bar{r}$) becomes about 1.1 or more, so that a particularly high $\bar{r}$-value is not required. To minimize earing, i.e., to provide the non-earing property, low planar anisotropy (Δr) for the r-value has also become necessary.[15-17]

The deformation that occurs when a steel sheet is blanked into a disc and a cup is formed by drawing the disc substantially comprises radial elongation and circumferential compression. Compressive deformation is particularly high in the peripheral region and this deformation results in through-thickness and radial strains. The r-value is defined as the ratio of the transverse strain to through-thickness strain in a uniaxial tension state. When a steel sheet with large Δr is drawn, flow-in of the material proceeds in the direction with a low r-value, and the valley of the ear is formed. This is because compressive deformation is smaller in this direction than in the direction with a high r-value, and hence, the deformation of the sheet thickness is larger in this direction. Conversely, compressive deformation is larger in the direction with a high r-value than in the direction with a low r-value, and material flow-in does not proceed, with the result that the crest of the ear is formed. Furthermore, the circumferential variation in sheet thickness is large and the accuracy of the cylinder diameter decreases. For this reason, earing is high in a steel sheet with large Δr and the required can height cannot be obtained. In this case, therefore, it is necessary to increase the original disc diameter, with the result that the yield decreases. In addition, the ear is so strongly pressed by the drawing operation that knife edges form, resulting in breakaway pieces that adhere to the die and damage the can surface. If the accuracy of the cylinder diameter decreases, circumferential buckling (wrinkling) is prone to occur with the necking operation, making it difficult to increase the necking rate.[4]

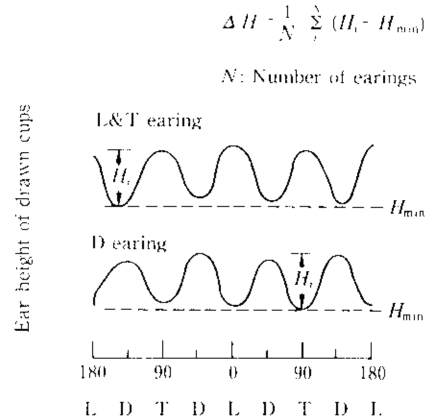

Fig. 1 Definition of the mean ear height ($\Delta\bar{H}$) of drawn cups (0° (L), 90° (T), and 45° (D) directions to the rolling direction)

Table 2 Relation between hot rolling temperature, mechanical properties and morphology of ferrite grain in double cold-reduced materials

Hot rolling temperature		Mechanical properties				Ferrite grain	
FDT (°C)	CT (°C)	Thickness (mm)	Tensile strength (MPa)	Elongation (%)	Hardness (HR30T)	G.S. No.	Aspect ratio
770	545	0.183	573	0	77	11.5	11.3
770	618	0.183	560	3	76	11.0	10.7
850	550	0.184	596	1	77	11.3	11.5
845	620	0.182	605	2	78	10.7	11.0

2.1 Effect of Hot Rolling Temperature on Earing

An experiment was conducted on a low-carbon aluminum-killed steel by varying the finishing delivery temperature (FDT) in the hot rolling process above and below the Ar_3 transformation point, and by varying the coiling temperature (CT). Continuous annealing was conducted after the sheet thickness had been reduced to 0.244 mm by the first cold reduction. Work hardening was accomplished by the second cold reduction, and the TMBP was finished to a thickness of 0.183 mm (25% rolling reduction) to produce TFS. The effect was evaluated by measuring the r-value according to the magnetostrictive oscillatory method[18] (JIS G3135) and the mean ear height ΔH (the definition is shown in **Fig. 1**) that was produced in each cup formed according to the cupping test method.[19] Incidentally, to cause the earing direction to correspond with Δr, ears formed in the 0° direction relative to the rolling direction were named L-ears, those formed in the 90° direction were named T-ears, and those formed in the 45° direction were named D-ears. The sign convention used for the height of the L- and T-ears is positive, and that of the D-ears is negative.

Table 2 shows the relationships between the hot rolling temperatures (FDT and CT) and the tensile strength, hardness and grain size. **Figure 2** shows the effect of the hot rolling temperatures on the $\bar{r}$-value, Δr and $\Delta\bar{H}$, while the appearance of the drawn caps is shown in **Photo 1**. The X-ray reflection intensity ratios of the four typical crystal planes—(222), (211), (200) and (110)—parallel to the rolling plane were measured to relate to the planar anisotropy of the r-value, these values being plotted against the hot rolling temperatures in **Fig. 3**. Although the grain size varied according to the hot rolling temperatures (FDT and CT), it had little effect on the tensile strength and hardness. It appears that this was because work hardening by the double-cold-reduction process greatly governed the mechanical properties. It was found that the $\bar{r}$-value was high with high FDT and medium CT, and that Δr and $\Delta\bar{H}$ were small under these conditions. This corresponds to the effect on texture that, under the conditions of a high

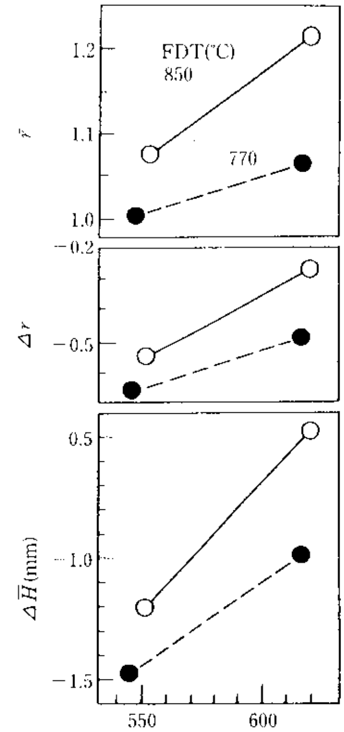

Fig. 2 Effect of the hot rolling temperature on $\bar{r}$-values, planar anisotropies (Δr) and the mean ear height ($\Delta \bar{H}$) of drawn cups

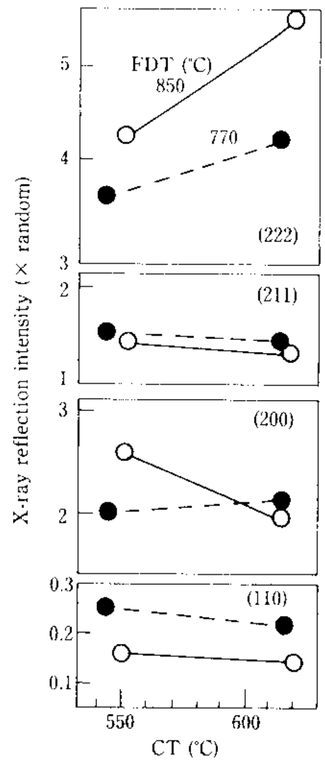

Fig. 3 Relationship between the hot rolling temperatures and the textures of double cold-reduced materials

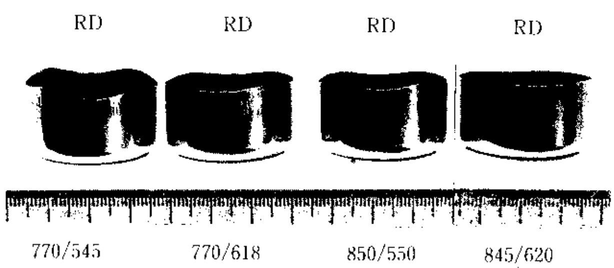

Photo 1 Appearance of the drawn cups

FDT and a medium CT, the (222) reflection intensity was high, while the (110) reflection intensity was low. From the appearance of the cups, it is apparent that earing was pronounced with many wrinkles on the cup walls at low FDT and CT, while both earing and wrinkling were small at high FDT and medium CT, resulting a good finish.

The r-value was influenced by the hot rolling temperatures. When FDT was below the Ar_3 transformation point, the {110} ⟨001⟩ orientation was strong in the hot-rolled sheet. When the hot-rolled sheet was then annealed after cold reduction, the {110} orientation remained, impeding the growth of the {111} orientation.[20] When FDT was above the Ar_3 transformation point, however, a more random orientation resulted in the hot-rolled sheet, and annealing caused the {111} orientation to develop and suppressed the {110} orientation, with the result that the r-value was improved with both Δr and $\Delta \bar{H}$ decreasing. At medium CT, carbides coalesce to increase the grain size and, at the same time, the precipitation of AlN was also promoted; as a result of this, solute carbon and solute nitrogen decreased, resulting in high cleanliness of the base metal. It seems that the {111} orientation after cold reduction and annealing developed as a consequence of this.

2.2 Effect of Cold Rolling Reduction on Earing

The second rolling is conducted with a high reduction for tempering to adjust the flatness and surface roughness of TMBP and, at the same time, to give the finished sheet high strength. The effect of the cold rolling reduction before annealing on the r-value is well known.[20] However, the relationship between the reduction of the second cold rolling conducted after annealing and the r-value is not well known. It was expected that the r-value would be changed by the reduction of the second cold rolling. Therefore, the effect of the first and second cold rolling reductions was investigated in order to obtain non-earing steel sheets as a material for DRD cans.

An aluminum-killed steel whose carbon content was low to improve earing was used, and hot rolling was conducted under high FDT and medium CT conditions. The first cold rolling was conducted with two cold rolling reductions of 88% and 86%, while the second cold rolling reduction was varied between 0 and 40%. To make a comparison, a cold-rolled, deep-drawing-quality steel sheet was also used; this steel sheet was cold rolled with a first reduction of as low as 70%, different from the thickness specification of the double cold-reduced TMBP, and finished by batch annealing. The ear profile was also evaluated.

The relationship between the double cold-rolled reduction and $\Delta\bar{H}$ is shown in **Fig. 4**, and the results of the ear profile measurements are shown in **Fig. 5**. In the double cold-reduced steel sheet, $|\Delta\bar{H}|$ was increased slightly with rolling reductions of 0 to 20%, and greatly with rolling reductions above 25%. In the cold-rolled, deep-drawing-quality steel sheet with a low reduction for the first cold rolling, $|\Delta\bar{H}|$ was decreased with increasing rolling reduction and tended toward non-earing property.

In the double cold-reduced steel sheet, four ears occurred in the D-direction after annealing, and the same D-direction ears were formed even with high rolling reduction. In contrast to this, the cold-rolled, deep-drawing quality steel sheet showed four ears in the L- and T-directions. In this steel sheet, the L- and T-direction ears were both decreased with increasing rolling reduction, and a D-direction ear appeared when the rolling reduction was increased to 40%.

The relationship between the X-ray reflection intensity ratios of the four main planes and the double cold-rolled reduction is shown in **Fig. 6**. In the 88% double cold-reduced steel sheet, the intensity of the (222) plane decreased progressively with increasing rolling reduction, and that of the (110) plane also decreased. In the cold-rolled, deep-drawing-quality steel sheet with the 70% reduction, the intensity of the (222) plane was high before the second rolling, and was increased further with increasing reduction in the second cold rolling.

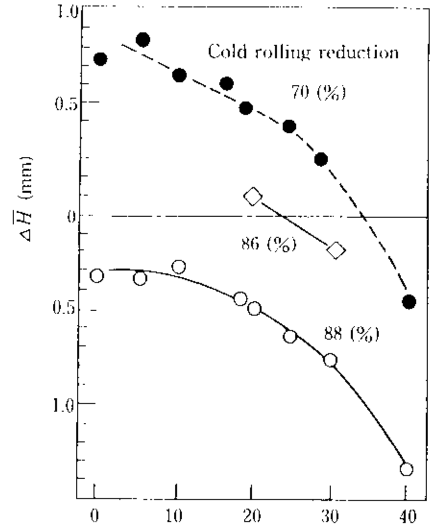

Fig. 4 Relationship between the double cold rolling reduction of sheets and mean ear height ($\Delta\bar{H}$) of the drawn cups

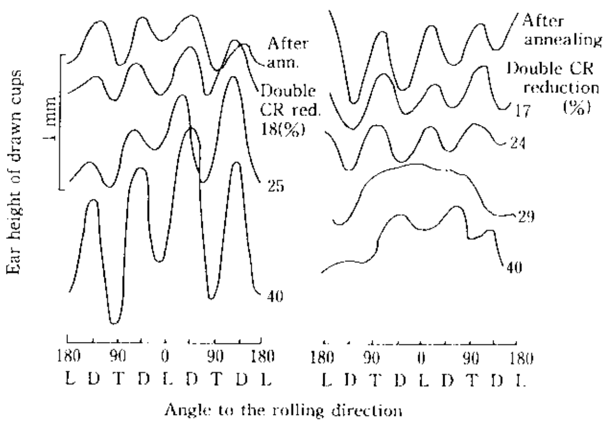

Fig. 5 Relationship between the rolling direction, double cold rolling reduction and the ear height of drawn cups

However, the intensity of the (110) plane decreased with increasing reduction in the second cold rolling. Therefore, the difference in earing characteristics corresponds well with the change in intensity of the (222) plane. It seems that the increase in intensity of the (222) plane result in a decrease in the {110} ⟨001⟩ orientation that causes L- and T-direction ears, and in the {100} ⟨011⟩ orientation that causes D-direction ears.

As shown in Fig. 4, the cold-rolling reduction was increased to 86% in the specification for double cold-reduced TMBP, and earing was markedly reduced. It seems that this was because L- and T-direction ears

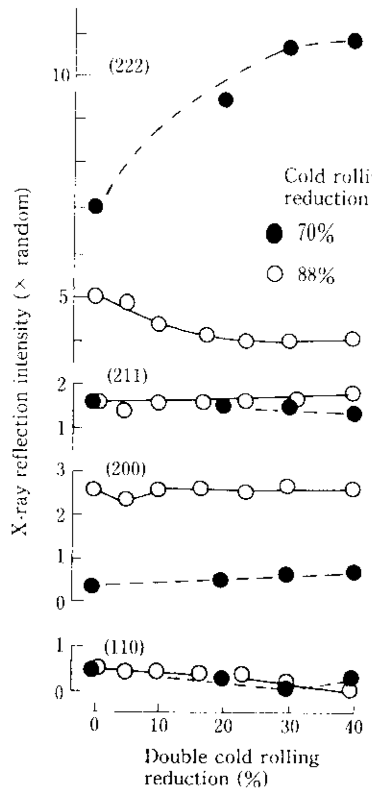

Fig. 6 Relationship between the textures and double cold rolling reduction

which occurred in the process up to annealing, and D-direction ears which were formed by subsequent rolling counteracted each other, with the result that a non-earing character was approached.

It is known well that Young's modulus, r-value and their planar anisotropy depend greatly on the texture of a steel sheet. In the present study of double cold-reduced TMBP, it was also found that the size of the ears which resulted from drawing was closely related to the texture.

2.3 Application to DRD Cans

Ultra-thin-gage, high-strength TMBP for DRD cans with deep drawability and non-earing property was produced by conducting hot rolling at high FDT and medium CT, and controlling the cold-rolled reduction to relatively low levels in both the first and the second rolling operations on low-carbon, aluminum-killed steel.

The resulting steel sheets had a temper grade of DR8 (HR30T 73) and high strength with a proof stress of 550 MPa or more, a low thickness of 0.18 mm, and high deep drawability ($\bar{r}$-value of 1.1 or more) with non-earing property.

A saving of about 14% in the empty can weight compared with conventional TMBP could be achieved with this ultra-thin-gage, high-strength TMBP.

3 Development of Ultra-Thin-Gage, High-Strength TMBP for DWI Cans

Tinplate with a matt surface finish (JIS G3303) is used as the steel sheet for DWI cans. This tinplate is produced by plating the dull surface of the base steel with tin to facilitate drawing and wall ironing, the tin-remelting and alloying treatment (a heat treament that involves melting tin in a short time and rapidly cooling after electrotinning) being omitted to prevent the formation of a hard Fe–Sn alloy phase. To make long beverage cans, the material needs to possess high drawability, with ironing and necking property and flange formability. The material must also provide high buckling resistance for the can bottom to withstand internal pressure and high strength to withstand column loading of the can body.

When DWI cans were first manufactured, priority was given to the formability of the tinplate used as the material. Therefore, thick-gage soft-temper TMBP with a heavy tin coating weight was used.[21,22] For example, the standard material had a tin coating weight of #50 (5.6 g/m^2), a sheet thickness of 0.34 mm and a temper grade of T1 (HR30T 49). The subsequent progress in can-making technology resulted in a decrease in the tin coating weight to #25 (2.8 g/m^2) and sheet thickness to 0.24 mm, but it was necessary to use hard tinplate of a high temper grade to provide adequate can strength with the reduced wall thickness. However, conventional hard-temper tinplate had a lower $\bar{r}$-value and larger Δr than soft-temper tinplate, and was inferior in earing property. As a result, productivity was impaired[4] because (1) earing was high, (2) circumferential buckling (wrinkling) was likely to occur, and (3) when the can was separated from the punch after ironing, the edges were prone to the roll-back phenomenon with resulting deterioration in the stripping characteristics.

Accordingly, it became necessary for the high-strength TMBP for DWI cans to be as soft as possible during DWI working, to provide an $\bar{r}$-value higher than about 1.3, to have non-earing properties with small Δr, and to gain strength from the subsequent heat treatment process.

3.1 Effect of Carbon Content on Earing

The soft-temper TMBP used as the starting material for tinplate for DWI cans was produced from a low-carbon, aluminum-killed steel with appropriately controlled carbon, aluminum and nitrogen contents by causing cementite to precipitate finely, making the ferrite grains fine, causing aluminum and nitrogen to dissolve in the hot rolling process, and by using the batch annealing process to precipitate fine AlN in the initial stage of recovery and recrystallization. As a result, pancake-like elongated grains were formed by annealing, and the {111} recrystallization texture developed. Therefore, this steel sheet offers high deep drawability. Furthermore, because annealing is conducted at a high temperature and for a long time, the grain size is large and nitrogen is fixed as AlN. In addition, the cooling rate is very low at about 20°C/h, so that almost all the carbon in the solid solute condition at high temperature is precipitated as cementite during the cooling process, resulting in the amount of solute carbon being decreased to less than 1 ppm. Consequently the residual amounts of solute carbon and nitrogen are small, and a non-aging, soft-temper TMBP is obtained. For this reason, it was difficult to apply this steel sheet to light-weight, thin-wall cans.

The continuous annealing process involves uncoiling the coiled steel strip, the required amount of heat always being stably provided for the necessary period of time, and it is possible to endow the strip with uniform mechanical properties, thus yielding quality and economic advantages. However the thin gage of the steel sheets for cans limits high-temperature annealing, the grain size decreasing and growth of the {111} texture being slow, so that these steel sheets tend to not to have the required deep drawability. However, because both the heating rate and the cooling rate are high, the solute carbon and nitrogen remain, and it is easy to produce hard steel sheets with the strain-aging property which are suitable for the manufacture of light-weight, thin-gage products.

Therefore, a study was made of the conditions for manufacturing a hard tinplate that would provide adequate can strength, and have high deep drawability and the non-earing property by applying the continuous annealing process. There are three methods for making steel hard: obtaining ultra-fine grains by increasing the carbon content and, at the same time, causing solute carbon to remain; causing a large amount of solute nitrogen to remain by adding excess nitrogen; and appropriately combining these two methods.[23] The method for making the grain size small by increasing the carbon content is not practical, because it would adversely affect the cold rolling workability. However, because it was expected that an increase in the nitrogen content would have little effect on the cold rolling workability, a method was sought to improve the deep drawability and non-earing property by making the steel hard with added nitrogen.

A low-carbon, aluminum-killed steel with a low aluminum content and high solute nitrogen, resulting in good strain-aging characteristics, was tested. To investigate the effect of the carbon content on the cold rolling workability and r-value, the carbon content was varied between 0.01% and 0.07%. For hot rolling, FDT immediately above the Ar_3 transformation point and medium CT were adopted to improve the r-value. After cold rolling, the heating cycles used for continuous annealing had the following two levels: a medium annealing temperature (750°C) immediately above the A_1 transformation temperature to increase the grain size as much as possible, and a low annealing temperature (720°C) to ensure stable operation. Temper rolling was conducted on a dull surface with a reduction of 1.5%, the steel sheet being finished with a tin coating weight of 2.8 g/m^2 and a matt finish without using the tin-remelting and alloying treatment.

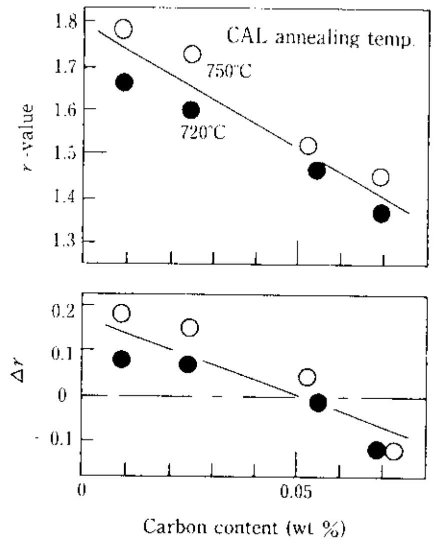

Fig. 7 Effect of carbon content and continuous annealing temperature on $\bar{r}$-values and their planar anisotropy (Δr) of tinplates

The effects of the carbon content and continuous annealing temperature on the $\bar{r}$-value and Δr of this tinplate are shown in **Fig. 7**. The $\bar{r}$-value was improved with decreasing carbon content. For Δr, the value changed from negative to positive with decreasing carbon content, so that a condition at which Δr became zero existed. The effect of the continuous annealing temperature was small. The hardness ranged from 58 to 62 (HR30T), and the temper grade was equivalent to T4. At a carbon content of 0.07% and less the cold rolling workability was adequate to provide the usual productivity. From the foregoing experiment results, it is apparent that a hard steel sheet with a high $\bar{r}$-value (about 1.5) and the non-earing property could be obtained from a steel with the carbon content ranging from 0.04 to 0.06% by hot rolling at high FDT and medium CT, and then applying continuous annealing after cold rolling at a temperature just below the A_1 transformation point.

3.2 Increasing the Buckling Resistance of the Can Bottom to Internal Pressure in the Can-Making Process

The effect of the annealing process on increasing the can strength was investigated for tinplate with a large residual amount of solute nitrogen. In the manufacturing process for DWI beverage cans with an inner

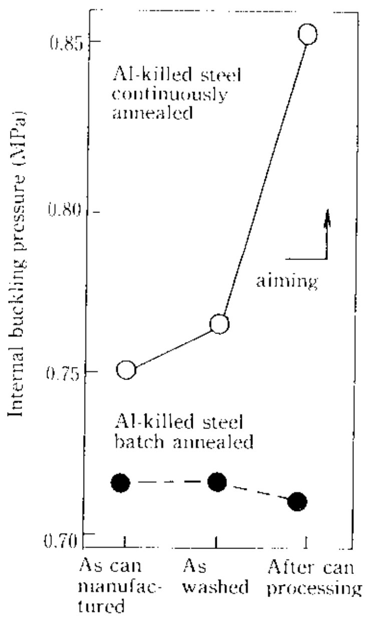

Fig. 8 Effect of the annealing process on the internal buckling pressure of can bottom processed in DWI can manufacturing

volume of 350 g in 0.24-mm-thick tinplate, the change in buckling resistance to internal pressure of the can bottom was investigated immediately after ironing, washing with warm water, a heat treatment (50°C) corresponding to the surface treatment, and a heat treatment (210°C) corresponding to baking in the painting and printing process. A comparison was made between batch annealed and continuously annealed steel sheets, with the results shown in **Fig. 8**. The batch-annealed steel sheet was soft and had non-aging characteristics, so that the strength immediately after ironing was low and scarcely increased even after heat treatment. The continuously annealed steel sheet, however, had high strength immediately after ironing, which gradually increased after that and exceeded the buckling resistance necessary for an internal pressure of 0.74 MPa. Although the column strength necessary to prevent fracture in the height direction of the can is 1 470 N or more, this strength was 1 950 N in the batch-annealed soft-temper TMBP, and 2 300 N in the continuously annealed hard-temper TMBP. Therefore, it was found that the continuously annealed hard temper TMBP had sufficient strength.

The phenomenon by which heat treatment of a worked steel above room temperature results in an increase in the yield strength and hardness, and elongation of the yield curve is known as strain aging. The metal grains immediately after working include many dislocations introduced by plastic deformation. Although these dislocations form mutual elastic stress fields, short-range slip motion is easy and deformation can be easily induced. However, when an aging treatment on a steel is conducted at a high enough temperature for the solute carbon and nitrogen to move, although the distribution of dislocations changes little, carbon and nitrogen atoms diffuse into the dislocations, forming the Cottrell atmosphere, with the result that the dislocations cannot move easily so that the steel becomes hard.

3.3 Increasing the Buckling Resistance of the Can Bottom to Internal Pressure in the Beverage Packing Process

DWI cans were initially used to pack beverages containing carbon dioxide. However, the technique for liquid nitrogen filling was developed in 1982,[24-26] and DWI cans also began to be used for packing non-carbonated beverages. Although the filling temperature of carbonated beverages is low, most non-carbonated beverages are retort-treated at a temperature above 90°C, tea being retort-treated at 115-125°C. During this high-temperature sterilization treatment, some can bottoms with low thickness have buckled due to insufficient strength;[27] therefore, the relationship between the buckling resistance to internal pressure of the can bottom at high temperatures for various tinplate materials was investigated.

The high-temperature tensile property of soft-temper and hard-temper tinplates was investigated by combining an Instron type of tensile testing machine with an infrared heating furnace. The test temperature ranged from room temperature to 210°C, which corresponds to the baking temperature in the painting process. The specimen used had a width in the reduced section of 10 mm and was 30 mm long. The test was conducted at an elongation rate of 10 mm/min, and when a clear yield point did not appear, the 0.5% proof stress is regarded as the yield stress.

The stress-strain curves obtained from the high-temperature tensile test are shown in **Fig. 9**. A yield point did not appear for the batch-annealed steel sheet, both the yield stress and maximum stress decreasing with increasing temperature. With the continuously annealed steel sheet, however, the yield point is apparent and the serration phenomenon occurred, the stress increasing with increasing temperature. It was found, therefore, that a hard-temper tinplate containing solute carbon and nitrogen was also advantageous for maintaining buckling resistance to the internal pressure at high temperatures.

Plastic deformation occurs by the movement of dislocations due to the external stress applied. There is a force resisting the motion of dislocations called the Peierls force[28] caused by the systematic arrangement of atoms in the metal crystal itself. The dislocations can move by overcoming this resistance when thermally activated, so that motion of the dislocations is easy at high temperatures and the deformation stress decreases. In non-aging steels containing little amount of solute carbon and nitrogen, the dislocations move easily due to

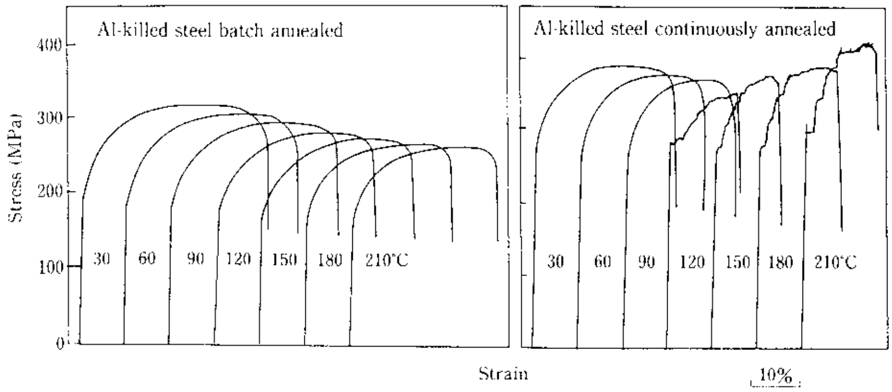

Fig. 9 Stress-strain curves observed in high-temperature tensile test

thermal activation and the deformation stress decreases, with the result that the buckling resistance to internal pressure of the can bottom decreases as a result of the heat treatment due to high-temperature filling and retort heating. The change in buckling resistance can be explained by this.

Under specific conditions of temperature, amount of the solute element, deformation rate, etc., the deformation resistance may sometimes increase due to an increase in the temperature. When deformation occurs at temperatures above about 100°C in a steel sheet containing a large amount of solute carbon and nitrogen, locking of the mobile dislocations by the solute carbon and nitrogen and the occurrence of new mobile dislocations that occurs during deformation take place at the same time, and the serration phenomenon for the deformation stress becomes unstable. When this occurs, the deformation stress increases. The lower the deformation rate and the more amount of the solute carbon and nitrogen, the lower the temperature at which this phenomenon occurs; this is known as blue brittleness.

Therefore, in tinplate with the strain aging characteristics that contains large amount of solute carbon and nitrogen, the deformation stress increases in the temperature range of about 100 to 200°C, with the result that buckling is not likely to occur.

3.4 Application to DWI Cans

A TMBP material for long DWI cans was developed by applying to a low-carbon, aluminum-killed steel hot-rolling at high FDT and medium CT, and then continuous annealing at a low temperature to cause a large amount of solute nitrogen to remain. This steel sheet is a hard-temper tinplate with a temper grade of T4 and a proof stress of 340 MPa possessing high deep drawability ($\bar{r}$-value of 1.3 or more) and non-earing characteristics. In addition, this steel sheet also incorporates the strain aging property that can enhance can strength because of the increase in strength developed by the heat treatment process after can-making.

A weight saving of about 20% in terms of empty can weight compared with a conventional TMBP can be achieved with this new TMBP.

4 Conclusions

Ultra-thin-gage, high-strength TMBPs suitable for thin-walled DRD cans and DWI cans were developed.

(1) TMBP for DRD cans:
  (a) It was found that both deep drawability and non-earing property can be obtained by reducing the carbon content, using medium CT and controlling the cold rolling reduction in both the first and second rolling processes to a relatively low level.
  (b) This steel sheet provides a material for DRD cans of high-strength TFS with a temper grade of DR8, an $\bar{r}$-value of 1.1 or more, and non-earing property with small Δr.
  (c) A weight saving of about 14% in terms of the empty can weight compared with conventional TMBP can be achieved.

(2) TMBP for DWI cans:
  (a) The $\bar{r}$-value and Δr can be improved by using the continuous annealing process, and by controlling the carbon content to an appropriate range and CT to a medium level. Furthermore, the buckling resistance to internal pressure of the can bottom can be increased by hardening the material by a heat treatment after forming, this being based on the strain-aging phenomenon arising from a large residual amount of solute nitrogen.
  (b) This steel sheet is a hard-temper tinplate with a temper grade of T4, an $\bar{r}$-value of 1.3 or more, and non-earing property. In addition, this steel sheet also incorporates the strain-aging property that can maintain adequate can strength, and provides a good material for long DWI cans.
  (c) A weight saving of about 20% can be achieved in terms of the empty can weight compared with conventional TMBP.

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