KAWASAKI STEEL TECHNICAL REPORT
No.42 (May 2000)

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A method which uses a highly efficient continuous annealing process for manufacturing hard- or soft-tempered ultra-thin steel sheets (in mill black plates) having excellent formability, for cans, has been developed. It has become clear that soft-tempered black plates of T1 toT2 grades, having excellent formability, can be manufactured by the use of an ultra-low carbon steel, even with a rapid heating-and-cooling continuous annealing process, whereas, a rather harder T2.5 to T3 grade black plates are similarly manufactured by adding a small amount of a solid-solution strengthening element, Mn, to the same ultra-low carbon steel. These newly developed black plates are superior in deep-drawing formability, elongation and flanging property and are expected to contribute to the lessening of material sheet thickness. Stable production of hard tempered black plates of T5 or greater grade can be conducted by adding N. The added N, by its solid-solution hardening and strain-aging hardening phenomena, effectively contributes to the increase of can-body strength and this enables the reduction of material plate thickness. Fluting (bending pattern), occurring during cylinder-shape forming, has been found to be avoided by effectively using the history of the working conditions of canmaking process.

1 Introduction

Annual production of cans worldwide totals approximately 80 billion units (23 million tons, or more than 2 billion cases), and is said to include 1 200 types. By country, the United States produces approximately 20% of the total, showing amounts of production and consumption that far exceed those of other nations. Japan is also one of the world's leading producers of cans, and at the same time, is a representative can consuming nation.[1] In particular, beverage cans, such as juice and coffee cans, account for a large percentage in Japan, where beverage can production reached 39.9 billion units in fiscal 1996. Moreover, although the rate of increase has declined somewhat, production is tending to increase. Items which are classified as cans include these many beverage cans, a quantitatively rather small amount of food cans, and general purpose cans which are used in a variety of applications. Most of the sheet steels for cans which are used as the base material for these containers are the products referred to as tinplate and tin-free steel. Production of these products is approximately 16 million tons worldwide, with Japan producing 2.92 million tons.[2]

Metal containers, beginning with beverage cans, are broadly classified according to the manufacturing method as 2 piece cans and 3 piece cans. Two piece cans consist of two parts, a lid and can body, which are formed by various press forming methods, using the above-mentioned tinplate or tin-free sheet steels as materials. Conventionally, 2 piece cans are represented by DI cans (drawn and ironed cans) and thin drawn cans. The latter type was developed in recent years, and is formed by the stretch and draw forming method or the stretch and ironing method, which have seen increasing use in recent years. Thin drawn cans are manufactured by the dry press method, using PET laminated tin-free steel as the material. Although it is a distinctive feature of 2 piece cans that cans are coated and printed after forming, only printing on the outer surface is performed with thin drawn cans.

On the other hand, 3 piece cans are containers consisting of a total of three parts, the top and bottom lids and the can body, which is joined by a welding method

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or cementing method after the material is formed into a cylindrical shape, using sheet steel which has been coated and printed in advance of forming as material.[3-5) At present, the joining methods used are the welding method and the cementing method. As with 2 piece cans, 3 piece can products using sheet steel laminated with a PET film have been mass produced recently. In the field of beverage cans, which are used in large quantities, technical research is being actively conducted with the aim of achieving various types of rationalization, in addition to the basic performance of preserving the contents. For example, because gauge reduction and necking are being employed in order to reduce can weight, steel sheets which are capable of satisfying the property requirements of these method were necessary.[6)

Sheet steels for can use can be classified into the following three types, depending on the manufacturing method and mechanical properties.

(1) Soft tempered sheet steel which is manufactured by batch annealing after cold rolling using low carbon aluminum-killed steel as the material and possesses a non-aging property and excellent deep drawability.

(2) Soft tempered sheet steel which is manufactured by continuous annealing after cold rolling using ultra-low carbon aluminum-killed steel as the material and possesses a non-aging property and excellent drawability.

(3) Relatively harder tempered sheet steel which is manufactured by continuous annealing after cold rolling using low carbon aluminum-killed steel as the material and possesses an aging hardening property.

Among the above, products manufactured by continuous annealing have been adopted in a wider range of applications in recent years, because the continuous annealing process offers advantages in productivity and uniformity of material properties.

This paper discusses the methods of optimizing the mechanical properties of the base materials of soft tempered and hard tempered ultra-thin sheet steels as examples of the development of these ultra-thin sheet steels for containers.

2 Soft Tempered Ultra-thin Sheet Steel for Can Use

Sheet steel for can use which has a thickness of approximately 0.2 mm is called ultra-thin sheet steel. With this material, as with other types, continuous annealing is now required because the continuous annealing process provides substantially higher productivity than the batch process, together with more uniform material properties. As a distinctive feature of the continuous annealing process, the high cooling rate after annealing means that solute C is easily retained in the material, which facilitates hardening. With the hard temper grades, T4–T5 (61±3 to 65±3 at HR30T), as specified in JIS G 3303, progress has been made in applying the continuous annealing process by taking advantage of this feature.[7) In contrast, with the soft temper grades, it is not easy to reduce the content of solute C. It was therefore necessary to use long over-aging, high temperature coiling in hot rolling, or other techniques, and application of the continuous annealing process was difficult. However, a technology was developed for obtaining soft tempered sheet steels equal to or better than the convention batch annealed product with the continuous annealing process, by using ultra-low carbon steel, which has a C content on the order of 20 ppm, as the base material. At present, soft tempered ultra-thin sheet steels of temper grades T1–T3 (49±3 to 57±3 HR30T) and coated sheets of the same material are being mass produced by this method.[8) The application of these sheets is continuing to expand because they possess high tensile strength and r-values exceeding those of the conventional batch annealed product[9). Examples of the application of these sheets are shown in **Photo 1**. In spite of the fact that all of these examples are hard-to-form parts which receive severe forming, stable forming has been realized in all cases.

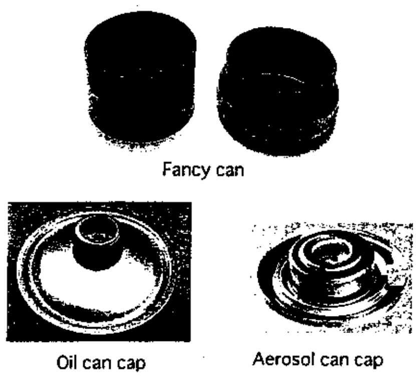

Photo 1 Example of the application of soft tempered tin plate

However, the following problems arise in the hot rolling process when manufacturing these formable ultra-low carbon sheet steels for can use. Because the thickness of the product is thin, the hot band is also thin, and stricter control of the rolling temperature, and control of the strip shape are important because the transformation temperature shows a relative increase in comparison with conventional low carbon steel (0.03–0.05%C content steel). Further, in the cold rolling process, rolling process, rolling at a large cold reduction ratio approaching 90% relative to the hot band becomes indispensable, requiring an excellent production technology which is capable of securing gauge accuracy and shape.

2.1 Principle of Manufacture and Features of Ultra-low Carbon Steel

It is known that the C content of steel is the factor

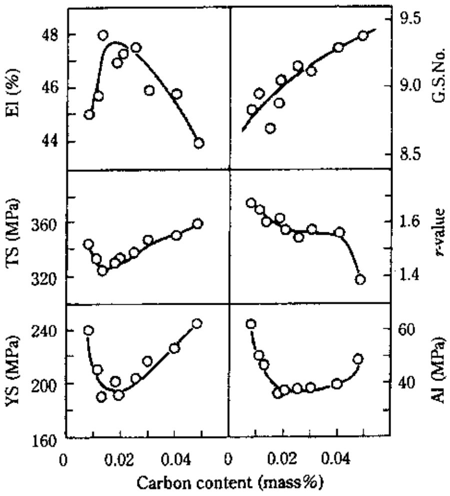

Fig. 1 Relation between the carbon content and mechanical properties

which has the largest effect on the mechanical properties of sheet steel. Accordingly, it is necessary to understand the behavior of C. **Figure 1**[10] shows the relationship between the carbon content of steel and the mechanical properties of cold rolled sheet steel. As the C content of the steel decreases, the strength of the sheet decreases and elongation and the *r*-value increase. This corresponds to an increase in the diameter of the ferrite grains and a decrease in the amount of cementite, which is a hard phase, and the improvement of the recrystallization texture which results from these changes. Further, a singular point exists at a carbon content of approximately 0.01%, and in this region, the increase in strength and decrease in elongation become remarkable. This is because the carbides which are present in the steel decrease sharply, and solute carbon loses precipitation sites and remains in the steel in large quantity. If the C content of the steel is reduced beyond this level, the content of solute C shows a steady decrease, resulting in a region where strength decreases steadily while elongation increases steadily. Optimization of the mechanical properties of the final product is achieved by appropriately controlling these features of the behavior of carbon in steel.

2.2 Properties Required in Ultra-low Carbon Steel for Cans in Soft Tempered Material

In sheet steels for can use, the highest priority is attached to the surface hardness, which is specified for business transactions. However, particularly in drawing applications, the property which is treated with the greatest importance in this regard is the Δr-value, which corresponds to the earing property. This in turn corresponds to the texture of the steel sheet, and is known to be influenced by the chemical composition of the steel and by operational factors such as the finishing rolling temperature in hot rolling and the cold rolling reduction

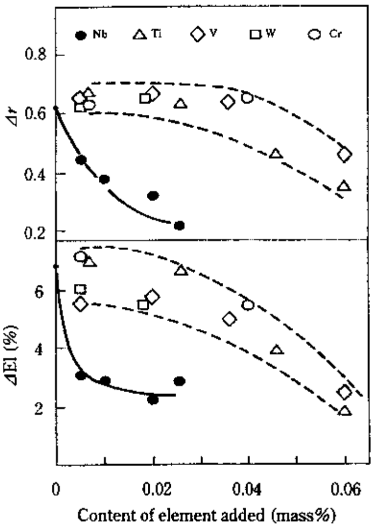

Fig. 2 Effect of the carbonitride forming element addition on the planar anisotropy of *r*-value and aging index

rate.[11] Conversely, earing behavior has also been estimated from the texture.[12,13] Because good appearance after forming is required, a fine microstructure which does not cause "orange peel" is necessary. A high *r*-value and elongation are also necessary in applications in which deep drawing is required. Furthermore, sheet steels for can use receive press forming after the sheet is coated and printed, in other words, after the sheet has been affected by aging due to heating. Thus, the product must possess an anti-aging property sufficient to prevent stretcher strain when press forming is performed.

2.3 Features of Manufacturing Method

One method of stably satisfying the property requirements described above is to reduce Δr and improve the anti-aging property by micro alloying of Nb, using ultra-low carbon steel as the base material.[14] The anti-aging property is evaluated in terms of the aging index (AI), which is the amount of increase in stress when 7.5% pre-straining is applied to a steel sheet, and tensioning is performed again after unloading. The effect of the addition of various carbo-nitride forming elements on Δr and AI is shown in **Fig.2**. Large improvement in planar anisotropy and improvement in the aging property are possible by Nb addition. The effect of the 1st cold rolling reduction rate on the Δr of continuous annealed material is shown in **Fig. 3**. Δr shows a peak at a cold rolling reduction rate of 70–80%, and also shows large positive values at all reduction rates with ultra-low carbon steel. In the manufacturing process for sheet steels for can use, the cold rolling reduction rate is 90% or higher in many cases. However, in this range of reduction rates, low carbon steel shows minus values of Δr. Therefore, with low carbon steel, it is necessary to reduce the cold rolling reduction rate, in other words, to

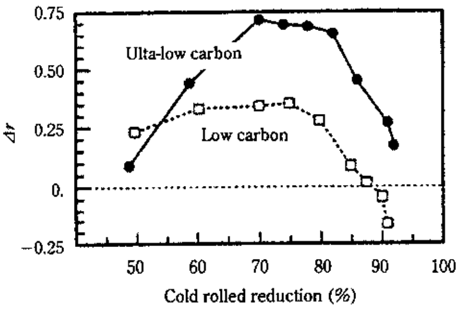

Fig. 3 Effect of primary cold-rolling reduction rate on the average r-value and planar anisotropy

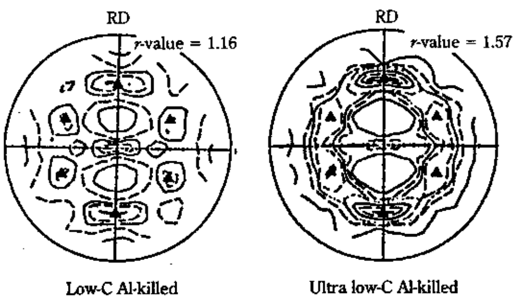

Fig. 4 Example of (200) pole figure of continuous annealed low-C and ultra-low C steels for cans

reduce the thickness of the hot band, in order to realize a non-earing property. On the other hand, with ultra-low carbon steel, addition of a small amount of Nb, as mentioned above, has the effect of reducing Δr. By combining this effect with an appropriate 1st cold rolling reduction rate, it is possible to obtain an optimum range within which Δr is virtually 0. The average r-value shows a tendency to increase in both low carbon steel and ultra-low carbon steel as the 1st cold rolling reduction rate increases. However, this increase is particularly large with ultra-low carbon steel, which is an advantage for obtaining a high r-value property. As shown in **Fig. 4**, this is due to the fact that the recrystallization texture has an extremely strong (111) orientation. This texture is largely unchanged even when cold rolling is performed after annealing in order to increase the hardness of the sheet. As described above, with normal hot rolling, cold rolling, and annealing, ultra-low carbon steel with a small Nb addition is a suitable material for high formability soft tempered sheet steel for can use. By applying ultra-low carbon steel, it is possible to manufacture temper grades T1 and T2 by light temper rolling after annealing. The method of applying rather high cold working to the material after annealing is also used to manufacture the intermediate temper grades T2.5 and T3. However, in spite of the fact that this process increases hardness, there are cases in which formability is sharply reduced due to an increase in the amount of

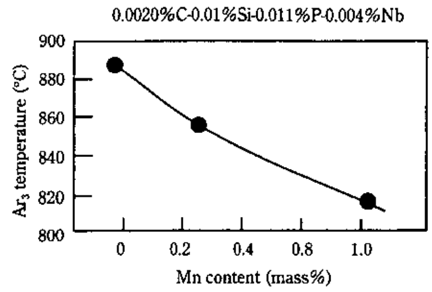

Fig. 5 Effect on Mn addition on the Ar_3 transformation temperature after hot-rolling

Table 1 Typical mechanical properties of the developed steel

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

Thickness: 0.25∼0.32 mm

spring back during forming, because yield strength is also markedly increased. By adding a small amount of Mn on the order of 0.5%, solid solution hardening and grain refining hardening of the steel can be obtained, making it possible to manufacture temper grades T2.5 and T3 using a low reduction rate in the temper rolling process after annealing. In this sheet steel, Mn has the effect of lowering the Ar_3 transformation temperature, as shown in **Fig. 5**, and therefore also has the advantage, in industrial operations, of making it possible to relax the finishing rolling conditions in the hot rolling process.[15]

2.4 Example of Mechanical Properties

An example of the mechanical properties of the above-mentioned sheet steel is shown in **Table 1**. Compared with the low carbon batch annealed steel which was used here for comparison purposes, the newly developed steel is expected to provide excellent punch stretchability, because it has more favorable elongation, and excellent deep drawability, because it has a higher r-value.[16] Although the crystal grain diameter is somewhat larger than that of the low carbon steel, this is not a problem for practical applications, and the aging property is also small.

Thus, it was confirmed that sheet steel with a small addition of Nb and Mn and an optimized temper rolling rate possesses excellent properties as a base material for DI cans, and is capable of satisfying the requirements of both gauge reduction and high necking property.[9,17–19]

As an example of formability, the results of an investigation of flanging formability, which is an important property in the can making process, are shown in **Fig. 6**. In comparison with conventional low carbon steel, ultra-

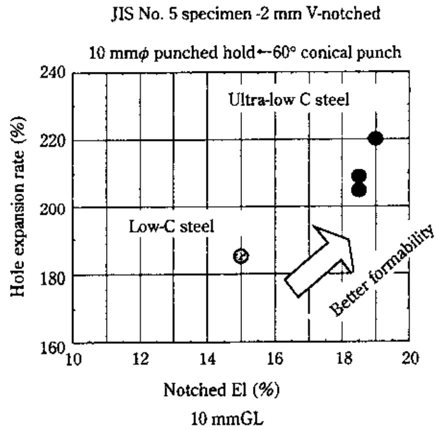

Fig. 6 Comparison of flanging formability of low C and ultra-low C steel sheets

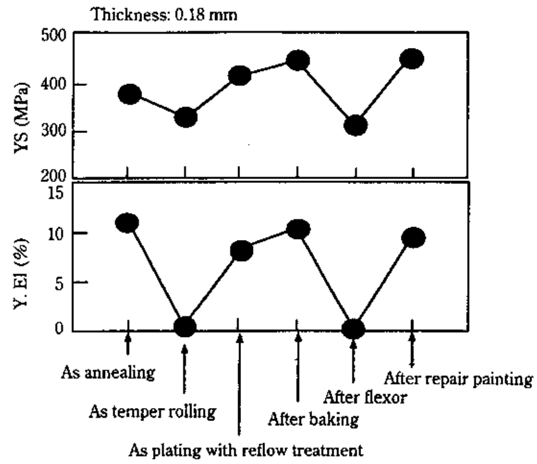

Fig. 7 Change of the mechanical properties of sheet steels during making can body

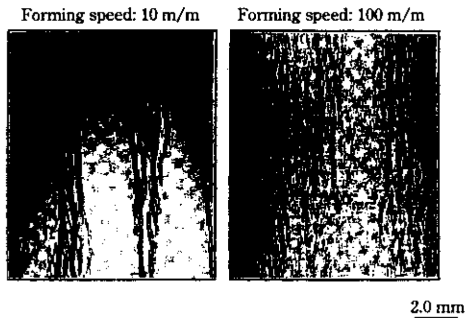

Fig. 8 Effect of forming speed on the appearance of can body with and without fluting phenomena

low carbon shows an excellent flanging formability. It is considered that the main factor in this is because, microstructurally, ultra-low carbon steel does not contain carbides, which become the origin of cracks, or because the low content of solute C results in improved local elongation.

3 Hard Tempered Ultra-thin Sheet Steel for Can Use

In the field of relatively hard tempered sheet steels for can use with temper grades of T4 and higher, harder temper, in other words, higher strength sheet steels are also required in order to achieve further gauge reductions in the base material. Gauge reductions have been achieved up to the present by increasing strength, as a result of a change from batch annealed material to continuous annealed material.

3.1 Principle of Manufacture

The methods described below are used to realize further increase in strength.

(1) The content of strengthening elements such as C, Mn, and others in the steel is increased.

(2) Work hardening is given to the material by applying an additional 2nd cold rolling step after annealing.

However, with method (1), the strength increase which can be obtained by adding C and Mn is relatively small, requiring an addition of approximately 0.1 mass% C and in excess of 0.5 mass% Mn. This gives rise to problems, because it causes a remarkable increase in flow stress in hot and cold rolling in the sheet production process, and thus makes it difficult to manufacture ultra-thin sheets. There are also problems when this type of material is used as a sheet steel for can making in welded can applications, because the welded joint shows remarkable hardening due to the hardening of the weld area which occurs in the welding process, and flanging formability is reduced.

Method (2) has the advantage of making it possible to reduce the sheet thickness simultaneously with strengthening of the sheet. However, there are also problems with this method in that the elongation of the material, and in particular, uniform elongation, is sharply reduced, and spring back increases due to a marked increase in the yield ratio.

As a means of solving the above-mentioned problems, research on materials for 3 piece cans was carried out in the direction of applying N, which is a strengthening element that had not been positively used in the past, to SR (single reduced) material. As a result, it became clear that this sheet steel does not cause rejections in the can making process, such as fluting (defects which occur during forming of the cylindrical can body), as originally feared, as a result of the increase in the aging property due to N addition. Rather, as shown in **Fig. 7**, in forming with soft temper grades, this new material has the extremely favorable feature of effectively realizing high strength by rapid strain aging after can making.[20,21) The effect of the forming speed on the morphology of fluting is shown in **Fig. 8**. It was found that the

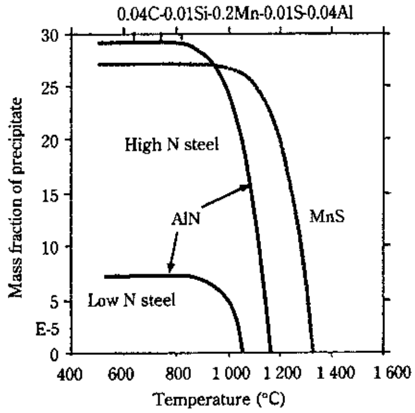

Fig. 9 Calculated equilibrium diagram of the precipitation for N added steel

deformed areas which appear in the fluting phenomenon form in a group of fine, bunched Luders bands, and the distribution of these bands changes markedly depending on the deformation speed. In other words, it is considered possible to recognize uniform deformation in which fluting does not occur in visual observation, if the Luders bands are distributed more uniformly and strain nonuniformity is reduced by conducting forming at a speed above a certain critical value, which is determined by the thickness of the steel sheet, forming dimensions, forming temperature, and other factors.[22] It has also been ascertained that the flexer (a mechanism which has a function analogous to a type of in-line leveler, and is considered to reduce the yield point and improve shape fixability by the Bauschinger effect, as a result of applying bending-straightening deformation to the sheet), which has been applied in many can making devices, is effective in suppressing fluting.

3.2 Outline of Manufacturing Method

With this sheet steel, it is necessary to ensure that the larger part of the N which was added to the steel remains in the solid solution state until the final product stage. For this, strict control of all process conditions, beginning with hot rolling conditions, is required. **Figure 9** shows the results of a thermo-dynamic calculation. Based on a thermal equilibrium condition, it was understood that, with low carbon aluminum-killed steel with a large amount of added N, N shows an extremely strong tendency to precipitate as AlN, and it is importain to avoid this and effectively and stably secur the amount of N in the solid solution state. Consideration of the fact that the diffusion of Al is rate controlling for the precipitation of AlN, and the fact that the solubility of N in ferrite is suffeciently large, suggests the imprortance of precipitation behavior in the high temperature region.

3.3 Mechanical Properties and Seam Weldability

Table 2 shows a comparison of the typical mechanical properties of the newly developed steel and those of a conventional steel. After aging treatment, which corresponds to baking after coating, the new steel shows a large increase in strength as a result of strain age hardening due to solute N. As the increase in the yield point stress due to N addition, a value of 2 360 MPa per 1 mass% N was obtained in research using a poly crystalline material of pure iron.[23] However, the increase in yield point stress in this sheet steel was 2–3 times larger than this value, and it is therefore assumed that not only simple solid solution hardening, but also strain age hardening were contributing factors.

The results of a measurement of the hardness distribution of a welded joint when seam welding was applied to a sheet steel with an N content of 100 ppm and a somewhat thick gauge of 1.0 mm are shown in **Fig. 10**. In comparison with a material with the conventional level of N, no significant hardening can be observed in the welded joint of the material which was strengthened by solute N by increasing the N content. Conventionally, the hardness of welded joints has been arranged in terms of the so-called carbon-equivalent, but there have been few clear reports with regard to the contribution of N. However, it was found that, at least with an N content on the order of 100 ppm, as in the present material, N has

Table 2 Typical mechanical properties of the developed steel comparing with conventional steel

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

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

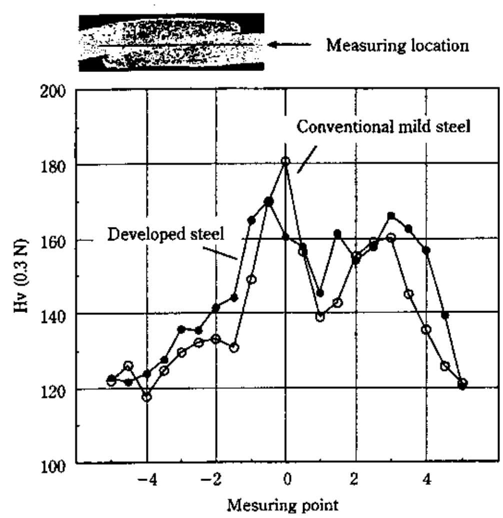

Fig. 10 Results of micro-hardness measurement of seam welded joint

little effect weld hardness.

From the above, sheet steel which employs solid solution hardening and strain age hardening by N addition has the following advantages as a material for use in 3 piece cans.

(1) Because strain hardening is not used, the new steel is superior in elongation in comparison with other materials of the same strength (hardness).

(2) The new steel shows no significant hardening of the welded joint due to the addition of N, and has better resistance to cracking during flanging forming after welding than sheet steels which are strengthened by C and Mn addition.

(3) High can body strength can be obtained by the strain age hardening phenomenon.

As described above, this sheet steel has a variety of excellent properties as an ultra-thin material for 3 piece cans, and is being widely used to achieve gauge reduction while maintaining the same level of can body strength.

4 Conclusion

Kawasaki Steel has developed formable ultra-thin sheet steel for can use produced by the continuous annealing process, which is superior in product quality and production efficiency. These sheets have the following features.

(1) With soft temper grade sheet steels, improvement of the aging property, refinement of the microstructure, and reduction of planar anisotropy have been achieved by adding a small amount of Nb to ultra-low carbon steel material.

(2) With the somewhat harder temper grades, T2.5 and T3, solid solution hardening and grain refinement hardening can be realized by adding a small amount of Mn.

(3) With ultra-low carbon steel, Mn addition lowers the Ar_3 transformation temperature, making it possible to relax the finishing rolling temperature condition during hot rolling.

(4) Ultra-low carbon sheet steel produced by the continuous annealing process shows superior elongation, drawability, and flanging formability in comparison with conventional low carbon steel.

(5) Hard tempered sheet steel for can use which is strengthened using solute N has a large strain aging hardening property and is therefore effective in increasing can body strength and achieving gauge reduction.

(6) At levels of up to approximately 100 ppm, N addition had no observable effect on seam weldability.

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