KAWASAKI STEEL TECHNICAL REPORT
No.41 (October 1999)
Advances in Iron and Steel Technologies,
Commemorating the 30th Anniversary of
Technical Research Laboratories

Recent Activities in Research of Steel Sheets

Osamu Furukimi

Synopsis :
The research and development activities of steel sheet in the last decade are reviewed by focusing mainly on a viewpoint of newly installed No. 3 hot strip mill at Chiba Works. The new products developed by using No. 3 hot strip mill are as follows: (1) Ultra high r-value cold-rolled sheet steel: Newly developed continuous and warm rolling technique combined with lubrication led to marvelously high r-value (r=3.0) cold rolled sheet steel. This steel has been applied to extra deep drawn shape parts. (2) TS/590 MPa hot-rolled dual phase sheet steel: Subdivided control valves in water cooling zone enabled to control cooling pattern precisely, which led to new hot-rolled high strength dual phase sheet steel. Mechanical properties, especially total elongation, have been much improved because of fine grains. (3) Hybrid dual phase sheet steel: Combination of the above mentioned dual phase steel and precipitation strengthening by using TiC in ferrite phase led to hybrid dual phase sheet steel. Hole expanding property and fatigue property have been greatly improved. (4) Highly formable thin steel for can use: Very thin and highly formable cold rolled sheet steel for can use has been developed using solute N. Improved product accuracy in strip gauge and crown using No. 3 hot strip mill backed up the development of the new products.

The body can be viewed from the next page.

Recent Activities in Research of Steel Sheets*

Osamu Furukimi
Dr. Eng., General
Manger, Sheet Lab.,
Technical Res. Labs

Synopsis:

The research and development activities of steel sheet in the last decade are reviewed by focusing mainly on a viewpoint of newly installed No. 3 hot strip mill at Chiba Works. The new products developed by using No. 3 hot strip mill are as follows: (1) Ultra high r-value cold-rolled sheet steel: Newly developed continuous and warm rolling technique combined with lubrication led to morvelously high r-value (r = 3.0) cold rolled sheet steel. This steel has been applied to extra deep drawn shape parts. (2) TS/590 MPa hot-rolled dual phase sheet steel: Subdivided control valves in water cooling zone enabled to control cooling pattern precisely, which led to new hot-rolled high strength dual phase sheet steel. Mechanical properties, especially total elongation, have been much improved because of fine grains. (3) Hybrid dual phase sheet steel: Combination of the above mentioned dual phase steel and precipitation strengthening by using TiC in ferrite phase led to hybrid dual phase sheet steel. Hole expanding property and fatigue property have been greatly improved. (4) Highly formable thin steel for can use: Very thin and highly formable cold rolled sheet steel for can use has been developed using solute N. Improved product accuracy in strip gauge and crown using No. 3 hot strip mill backed up the development of the new products.

1 Introduction

Steel sheets are used in a wide range of applications, such as automobiles, structural purposes, electrical equipment, and cans, and the requirements for these products have become extremely diverse, including range of thickness and width, surface condition, and mechanical properties. At the same time, customers in various industrial fields have also desired the development of steel sheets with far higher functions. On the other hand, looking at the steel sheet manufacturing process, rapid progress has been achieved in technologies which enable continuous production, such as continuous casting, continuous annealing, continuous hot rolling, and others. This report reviews the technical development of the last ten years, focusing mainly on the improvement of the mechanical properties of steel sheets by application of the continuous hot rolling process.

2 Continuation of Production Processes

In recent years, "continuation" has been one of the main tasks for technical innovation in the steel industry.

One such effort was the establishment of the continuous casting method, which offers great advantages not only in terms of savings of heat energy, but also in the control of material properties, because fluctuations in the chemical composition of the steel can be reduced to an extremely low level.

Next, continuous annealing technology should be mentioned. In comparison with the box annealing used to date, the continuous annealing process enables stable production of steel sheets with excellent homogeneity and surface condition with extremely high efficiency. Further, by applying rapid heating and rapid cooling processes, which are the strong points of the continuous annealing process, it has been possible to develop products with special features, beginning with high tensile cold rolled steel sheets. Examples of these products include low yield ratio (ratio of yield strength to tensile strength) steel sheets,[1] as represented by cold rolled ferrite-martensite dual phase steel, and extra deep drawing cold rolled steel sheets[2] which possess both an anti-aging property and bake-hardenability.

The next "continuation", following continuous an-

* Originally published in *Kawasaki Steel Giho*, **31**(1999)1, 23–27

nealing, was realized recently in the hot rolling process. The hot rolling process is represented by the tandem type hot strip mill, which has extremely high productivity. The first step in continuation of the hot rolling process is continuation and synchronization of the steelmaking and hot rolling processes, represented by CC-DR (continuous casting-direct rolling) and DHCR (direct hot charge rolling). By making use of these continuous processes, it has become possible to exercise a high level of control over the precipitation phenomena involving carbides and nitrides, and thus to improve the property of the material.

The second step in continuation of the hot rolling process is that of hot rolling itself. In hot rolling, the material is passed continuously through the roughing mill and a finishing mill comprising 6 or 7 stands, but basically, slabs are rolled one at a time. However, Kawasaki Steel's Chiba Works realized continuation in the finishing hot rolling process at the new No. 3 hot strip mill in 1996 in advance of any other mill in the world. The new process, called "endless hot rolling," is a technology which performs finishing rolling continuously by joining sheet bars that have completed rough rolling at the entry side of the finishing mill. This continuation of hot rolling has dramatically improved the material property of steel sheets.

3 New Products Manufactured by Application of Endless Hot Rolling

As mentioned above, continuation of hot rolling plays an important role in the improvement of mechanical properties. This section will introduce several products which are manufactured by application of this technology.

3.1 Ultra High r-Value Cold Rolled Steel Sheet

The deep drawability of steel sheets improves as r-value increases. This phenomenon is known to be closely related to the orientation of crystallographic structure.[3] To date, the r-value has been improved by applying optimized cold rolling and annealing conditions to ultra-low carbon IF (interstitial atom free) steel in which C and N are stabilized as precipitates by adding Ti and/or Nb. In such case, (111) texture, which is effective for deep drawability, can be obtained. The maximum r-value of steel sheets which are mass producted by this method is 2.4. However, the development of steel sheets with higher r-values, corresponding to the trend toward forming of integrated panels for automobiles, has been demanded for the past ten years. Moreover, it was known that the r-value of steel sheets after cold rolling and annealing generally shows a positive correlation to the r-value of the hot rolled steel sheet before cold rolling.[4]

In hot rolling, which is a passing process in the production of cold rolled steel sheets, a transformation from

Table 1 Typical mechanical properties of high r-value steel sheets

	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	$\bar{r}$-value
Newly developed high r-value steel sheet	150	280	55	3.0
Conventional high r-value steel sheet	150	280	55	2.4

austenite to ferrite occurs after hot rolling. As a result, the crystal orientation becomes random due to the change in the crystal structure, and it is not possible to obtain high r-values. When rolling is performed in lower temperature ferrite region to avoid structural randomization due to $\gamma \rightarrow \alpha$ transformation, strong friction between the strip and the rolling rolls causes strong surface shear deformation which leads to poor (111) texture.[5] A method of solving this problem is to reduce the surface shear layer by lubricated rolling. By performing lubricated rolling, the shear structure of the surface is reduced, allowing orientation of the (111) plane not only in the center of the sheet thickness, but also at the surface. On the other hand, it is also possible to produce steel sheets with ultra high r-values by performing cold rolling and annealing twice, but due to production line restriction on the sheet thickness, this method was limited to an r-value of approximately 2.4.

In January 1996, Kawasaki Steel began the world's first fully continuous hot rolling operation, which the company calls "endless hot strip rolling,"[6,7] at Chiba Works' new hot strip mill (3 HOT, started up in May 1995). By realizing fully continuous hot rolling, it became possible to perform heavily lubricated, heavy reduction rolling in the ferrite region, which could not be applied with the conventional hot rolling equipment due to problems of instability in rolling, such as meandering and slipping of the strip during rolling, and similar difficulties. The development of this technology suppresses additional shear deformation at the strip surface due to friction, which could not be avoided in conventional ferrite region rolling, and enables a high level of control over the crystallographic structure even after hot rolling, making it possible to produce cold rolled steel sheets with an ultra high r-value of 3.0, which exceeds the conventional level.[8,9] The representative properties of ultra high r-value steel sheets are shown in **Table 1** in comparison with the conventional cold rolled steel sheets having the highest level of r-values. These steel sheets can be applied to a wide range of extra deep drawing products such as oil pans.

3.2 High Tensile Strength 590 MPa Grade Dual Phase Hot Rolled Steel Sheets

Dual phase steel is a material in which islands of hard

Table 2 Typical mechanical properties of TS590 MPa grade hot-rolled dual phase steel sheets

t = 2.3 mm

YS (MPa)	TS (MPa)	YR (%)	El (%)	*n*-value	$\bar{r}$-value
304	617	49	31	0.23	~1.0

martensite are dispersed in a soft ferrite matrix. Because the yield ratio is small, this type of steel is excellent in formability and has the distinctive feature of high elongation.[10] In automotive applications, dual phase steel sheets are expected to be applied to reduce the weight of parts by using thinner material. Initially, dual phase steel sheets were produced by the cold rolling process, but subsequently, the development of hot rolled dual phase steel sheet was promoted. To replace cold rolled dual phase steels with hot rolled dual phase steels, there are two key points. Firstly, hot rolling technology for high strength steel must be established to obtain the same accuracy of thickness. Secondly, accurate cooling control should be achieved to control phase transformation after hot rolling.

In producting dual phase hot rolled steel sheets, control of the cooling condition after finishing rolling is one particularly important factor. Promoting the ferrite transformation by rapid cooling after rolling, followed by slow cooling, causes enrichment of C in the untransformed austenite, while the rapid cooling treatment which is performed subsequent to this causes the austenite to transform effectively into martensite. By applying the new No. 3 hot strip mill at Chiba Works, it has become possible to control this cooling process with high accuracy. **Table 2** shows the typical mechanical properties of newly developed TS 590 grade hot rolled steel sheet. Features of the new product include favorable elongation, which exceeds 30%, and low yield ratio of approximately 50%.

3.3 Hybrid High Strength Type Dual Phase Steel Sheet[11]

In order to achieve further reductions in the weight of automotive body, high strength steel sheets with a tensile strength of 780 MPa have been required. In the development of this product, the material should combine the material property advantages of phase strengthened steel and precipitation strengthened steel. The development was therefore carried out by a method of precipitation strengthening of the ferrite phase after producing a dual phase microstructure comprising ferrite and martensite. (The resulting product is called hybrid-type dual phase steel sheet). As the aims of the material design, the following four points can be mentioned.

(1) Precipitation strengthening of the ferrite phase reduces the strength difference between the ferrite phase and the martensite phase, and thus reduces the concentration of strain in the ferrite phase; this improves both the local elongation property and the flange elongation property.

(2) The advantages of low yield ratio and large uniform elongation possessed by dual phase steels are secured.

(3) The coexistence of precipitation strengthened ferrite phase and martensite phase, increases fatigue crack propagation resistance, and thus improves fatigue properties.

(4) The weld hardening property imparted to the material is good balanced in that weld area is not abnormally hardened, as in the case of phase hardened steels, and softening of HAZ (heat affected zone) does not occur, as in the case of precipitation strengthened steels.

Table 3 Chemical compositions of hybrid-type steel sheets

(mass%)

TS grade	C	Si	Mn	Ti	P	S	Al
690 MPa	0.06	1.25	1.45	0.08	0.010	0.001	0.030
780 MPa	0.08	1.50	1.80	0.10	0.010	0.001	0.030

Table 4 Mechanical properties of hybrid-type steel sheets

TS grade	YS (MPa)	TS (MPa)	YS/TS (%)	El (%)	Fatigue limit (MPa)	
					As hot-rolled	Surface grinded
690 MPa	516	688	75	25	319	392
780 MPa	558	828	67	21	343	462

In order to form the microstructure described above, it is important to promote two reactions in the cooling process following hot rolling. As the first, fine TiC, which has a large precipitation strengthening effect, should be formed rapidly in the ferrite grains immediately after the transformation from austenite to ferrite. As the second, the excess C which was not consumed as TiC should be made to concentrate on the austenite phase which remains at this point in time, and the formation of martensite in the subsequent cooling is facilitated.

Based on the above thinking, hybrid-type dual phase hot rolled steel sheets of TS690 MP grade and 780 MPa grade are produced using the new No. 3 hot strip mill at Chiba Works. The chemical compositions and their mechanical properties of these steels are shown in **Tables 3** and **4**, respectively.

The hole expansion ratio of these steels, as shown in **Fig. 1**, is superior to that of conventional dual phase steel and precipitation strengthened steel sheets. As mentioned above, this is because the strength difference between the ferrite phase and the hard phase of martensite is reduced by precipitation strengthening of the ferrite phase, which has the effect of suppressing the concentrations of strain in the ferrite grains during working.

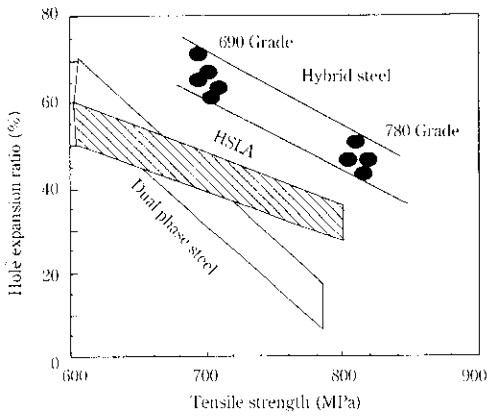

Fig. 1 Relation between the hole expansion ratio and the tensile strength of conventional and newly developed hybrid-type high strength steel sheets

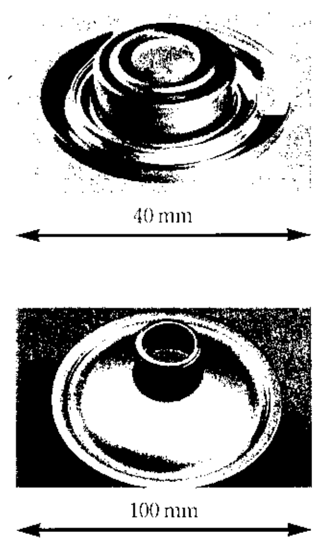

Photo 1 Examples of formed parts using formable thin-gauge steel sheets

3.4 High Formability Tin Plate for Can Use

With steel sheets for can use, which have a thickness of approximately 0.2 mm and are termed ultra thin steel sheets, there has also been expanded application of continuous annealing, which offers higher productivity and makes it possible to obtain uniform material properties. In the field of hard steel sheets with temper grades of T4–T5, continuous annealing can be applied with relative ease, but because of the high cooling speed in continuous annealing, solute C tends to remain in the material, and it has therefore been difficult to produce soft tempered tin plates. However, by using ultra low carbon steel with a C content of 20 ppm[12] as the base material, Kawasaki Steel has succeeded in obtaining soft tempered tin plates on the same level as the conventional box-annealed material even when using the continuous annealing process. At present, Kawasaki Steel uses this method in the mass production of soft tempered tin plates (grades T1–T3) and tin mill blackplates using the former products as the substrate. Because these steel sheets have elongation and r-values equal to or better than those of the conventional box-annealed steel sheets, their applications are continuing to expand.[13] Examples of the applications of this steel sheet are shown in **Photo 1**. In spite of the fact that both of these examples are extremely hard-to-form parts, stable forming is possible. In the production process of these highly formable, ultra low carbon steel sheets for can use, the sheet of the hot rolled steel is thin and the $\gamma \rightarrow \alpha$ transformation temperature shows a relative increase in comparison with conventional low carbon (0.03–0.05%) steel. Therefore, the precise control of the rolling temperature and the shape of the steel strip, becomes important in hot rolling. The new No. 3 hot strip mill at Chiba Works is contributing to high accuracy control of these hot rolling conditions.

Similar to automobile industry, high strength steels are required in can industry to reduce materials thickness and can weight. Up to present, thinner sheets have already been realized by increasing the strength of the material, which was achieved by changing over to continuous annealed process from box-annealed process. The methods of realizing further increases in strength are as follows.

(1) To increase the content of strengthening elements such as C, Mn, etc. in the steel.
(2) To apply work hardening by performing additional secondary cold rolling after annealing.

However, in method (1), it is a problem that both C and Mn increase deformation resistance during hot rolling and cold rolling. In addition, welded zone should be hardened in case of welded can applications, and flange formability should be reduced as well.

Method (2) has the advantage that the steel sheet is strengthened simultaneously when the thickness is reduced, but has the problems of markedly reduced elongation in the base matrial and increased spring back due to an increase in the yield ratio.

As a method of solving the above problems, new steel for 3-piece cans, was developed by applying the strengthening element N, which had not been positively used in the past, to SR (single reduced) material. As a result, it was found that these steel sheets did not show the fluting or other problems in response to the increase in the aging property accompanying N addition. Rather, as shown in **Fig. 2**, the sheets possessed the extremely good properties of being soft during forming, and then effectively realizing a high level of strengthening after canmaking as a result of rapid strain aging.[14,15] With this steel sheet, it is necessary to leave the larger part of the added N in a solid solution condition in the product.

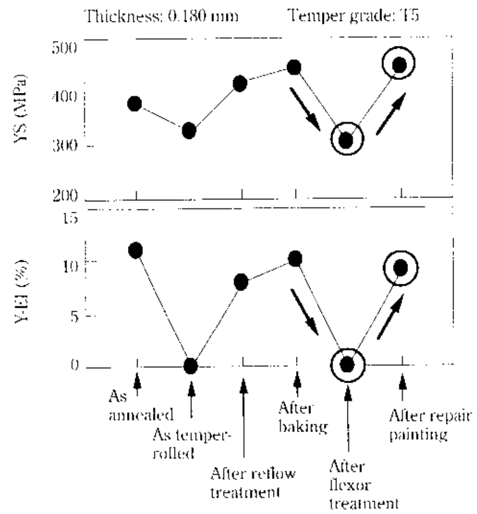

Fig. 2 Change of tensile properties of N solution strengthened thin-gauge steel sheets for can use during can manufacturing process

Therefore, the precise control of all processes including hot rolling is required. In this regard, the high accuracy control of rolling conditions at No. 3 hot strip mill is effectively used.

Table 5 shows a comparison of the representative properties of this N solution strengthened steel with those of the conventional product. After aging corresponding to baking following painting, the strength of the material shows a large increase due to strain aging hardening.

5 Conclusion

In the most recent 10 years, remarkable progress has been achieved in the continuation of steel sheet production processes, and in response, product development which makes use of the advantages of these processes has been promoted. As a result, not only has the quality of existing products improved, but a large number of new products have also been developed. In particular, the continuation of the finishing process in hot rolling, which was achieved recently, is an innovation which has dramatically expanded the degree of freedom in the development of steel sheet products. In the future, new product development based on this technology is expected in a wide range of fields.

Table 5 Typical mechanical properties of N solution strengthened thin gauge steel sheets for can use

Steel	As temper rolled			After aging (at 210°C)		
	YS (MPa)	TS (MPa)	El (%)	YS (MPa)	TS (MPa)	El (%)
Conventional	322	415	25	381	406	27
With 100 ppm N addition	331	454	26	442	462	27

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

References

1) K. Hashiguchi, M. Nishida, T. Katoh, and T. Tanaka: *Kawasaki Steel Giho*, **11**(1979)1, 68-77
2) S. Satoh, T. Irie, and O. Hashimoto: *Tetsu-to-Hagané*, **68** (1982)9, 1362–1368
3) R. L. Whiteley: *Trans. ASM.*, (1960)52, 154–169
4) K. Matsudoh and T. Shimomura: *Tetsu-to-Hagané*, **55**(1969), S535
5) S. Matsuoka, M. Morita, O. Furukimi, and T. Obara: *Tetsu-to-Hagané*, **83**(1997), 127–132
6) Y. Ogawa, T. Nakamura, and S. Kitao: *Kawasaki Steel Giho*, **27**(1995)3, 131–135
7) H. Nikaidoh, S. Isoyama, N. Nomura, K. Hayashi, K. Morimoto, and H. Sakamoto: *Kawasaki Steel Giho*, **28**(1996)4, 224-230
8) K. Tsunoyama: *Materia Jpn.*, **33**(1994), 20–23
9) K. Sakata, S. Matsuoka, T. Obara, K. Tsunoyama, and S. Shiraishi: *Materia Jpn.*, **36**(1997), 376–378
10) J. Mano, M. Nishida, T. Tanaka, T. Katoh, N. Aoyagi, and N. Yamada: *Tetsu-to-Hagané*, **68**(1982)9, 1297-1305
11) M. Morita, T. Shimizu, O. Furukimi, N. Aoyagi, and T. Katoh: *Materia Jpn.*, **37**(1998)6, 513–515
12) T. Obara, K. Sakata, K. Osawa, M. Nishida, and T. Irie: "Metallurgical Basis of Producing Continuous-annealed Low-Temper Tinplate", 363–383, Technology of Continuously Annealed Cold-rolled Sheet Steel, Edited by R. Paradhan; TMS AIME, Detroit, (1984)
13) K. Okuda, A. Tosaka, K. Sakata, O. Furukimi, K. Satoh, and H. Kuguminato: *Tetsu-to-Hagané*, **83**(1997)9, 569-574
14) A. Tosaka, M. Aratani, T. Obara, H. Kuguminato, and Y. Izumiyama: *Materia Jpn.*, **36**(1997)4, 379–381
15) A. Tosaka, M. Aratani, and H. Kuguminato: *Kawasaki Steel Giho*, **27**(1995)3, 169–179