Abridged version

KAWASAKI STEEL TECHNICAL REPORT

No.42 (May 2000)

Ultra-thin Hot Rolled Strip

Nobuo Yamada, Masanori Kitahama, Hideyuki Nikaido

Synopsis :

Kawasaki Steel has been making efforts to develop new hot-rolled steel products by using fully continuous rolling technology, so-called "endless rolling", at No. 3 hot strip mill of Chiba Works. Stable rolling technology of ultra-thin hot rolled strips such as 1.0 mm, 0.9 mm, and 0.8 mm in thickness has been established, and the conventional minimum gauge of hot rolled strips (1.2 mm) has been lowered. The ultra-thin hot rolled strips have been provided to the market with a brand name "RTHC" (River thin hot coil commercial grade) since 1977. The ultra-thin hot rolled strips have excellent quality in dimensional accuracy and mechanical properties. In addition, the ultra-thin hot rolled strips meet current needs of energy saving and reducing CO2 emission. New market and more demands for the newly developed product strips are expected.

The body can be viewed from the next page.

Ultra-thin Hot Rolled Strip*



Nobuo Yamada
Staff Manager,
Sheet Control Sec.,
Technical Control Dept.,
Chiba Works

Masanori Kitahama
General Manager,
Mechanical Processing,
Instrumentation & Control Lab.,
Technical Res. Labs.

Hideyuki Nikaido
Dr. Eng., Staff Manager, Hot Rolling Technology Sec., Hot Rolling Dept. and Equipment Technology Sec., Equipment Technology Dept.,
Chiba Works

Synopsis:

Kawasaki Steel has been making efforts to develop new hot-rolled steel products by using fully continuous rolling technology, so-called "endless rolling", at No. 3 hot strip mill of Chiba Works. Stable rolling technology of ultra-thin hot rolled strips such as 1.0 mm, 0.9 mm, and 0.8 mm in thickness has been established, and the conventional minimum gauge of hot rolled strips (1.2 mm) has been lowered. The ultra-thin hot rolled strips have been provided to the market with a brand name "RTHC" (River thin hot coil commercial grade) since 1977. The ultra-thin hot rolled strips have excellent quality in dimensional accuracy and mechanical properties. In addition, the ultra-thin hot rolled strips meet current needs of energy saving and reducing CO_2 emission. New market and more demands for the newly developed product strips are expected.

1 Introduction

The minimum thickness of the hot rolled steel strip has conventionally been 1.2 mm due to the difficulty of securing the finishing delivery temperature (FDT), threading problems when the head and tail ends of strips pass the finishing mill and on the hot run table, and other factors. Thus, in spite of the strong demand for the ultra-thin hot rolled strip with thicknesses or under 1.2 mm, which had been desired from the point of view of weight reduction and energy saving, the problems related to the rolling process had prevented the realization of such products.

In recent years, there have been reports[1)] that it is now possible to produce ultra-thin hot rolled strip using mini-mills which are designed specifically to roll thin and ultra-thin hot rolled strips. However, even mills of this type do not solve the problems of threading at the head and tail end of the strip,[2)] which remained inherent in the process as in the past.

As a fundamental solution to the problem of head and tail end threading, Kawasaki Steel developed the world's first endless rolling technology, in which sheet bars are joined at the entry side of the hot finishing mill and are supplied continuously to the hot finishing mill, at Chiba Works No. 3 hot strip mill (Chiba 3HOT).[3–5)] Because the endless rolling realizes steady rolling, in which a constant strip tension is maintained at all times, this technology makes it possible to the roll ultra-thin hot rolled strip stably.[6)]

This report describes the production technologies for ultra-thin hot rolled strip which substantially exceeds the limits of conventional rolling, the quality of the ultra-thin strips which are produced using this technology, and examples of the applications of new products.

2 Rolling Characteristics of Ultra-thin Hot Rolled Strip, and Characteristics of Equipment and Control Technologies

2.1 Rolling Characteristics of Ultra-thin Hot Rolled Strip

Conventionally, the detection of the rolling force properties during hot rolling has been an essential for producing the ultra-thin hot rolled products in the thickness zone which is normally manufactured by cold rolling. **Figure 1** shows the plastic constant (increased rolling force due to the thickness reduction per unit of strip thickness) and the change of rolling force due to a 1% change in thickness during hot rolling and cold

* Originally published in *Kawasaki Steel Giho*, **31**(1999)3, 155–160

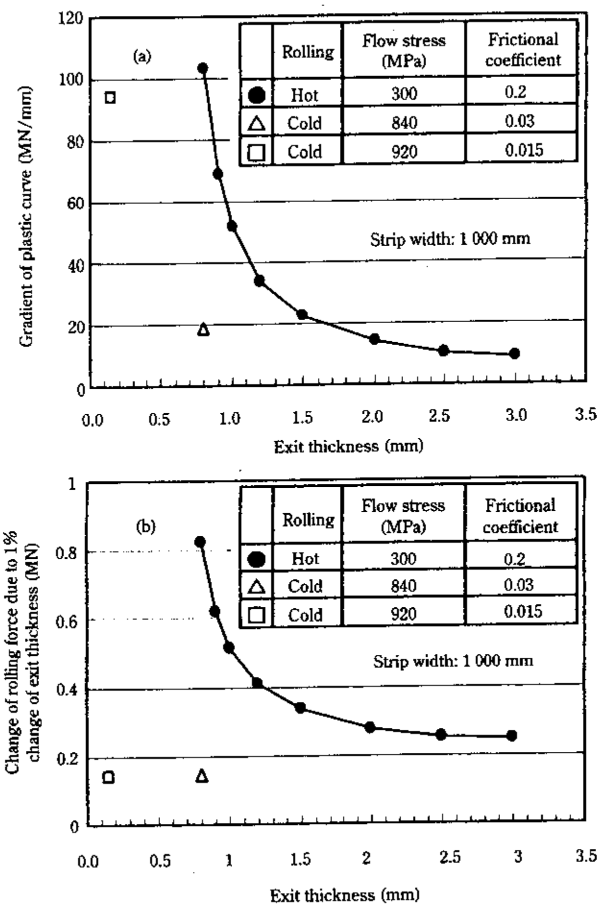


Fig. 1 Comparison of rolling force between hot and cold rolling: (a) Gradient of plastic curve, (b) Change of rolling force due to 1% change of thickness

rolling. The plastic constant increases as the strip becomes thinner, and in the case of ultra-thin hot rolled strips, is approximately twice as large with 0.9 mm strip as with 1.2 mm material, which is conventionally the minimum thickness for hot rolled strips. Moreover, with 0.8 mm strip, the plastic constant becomes roughly 3 times as large as with 1.2 mm strip. In cold rolling, the deformation resistance rises to approximately 1 000 MPa, reaching a value approximately three times as large as the 300 MPa in hot rolling. However, the effect of reducing the friction coefficient by the lubricated rolling exceeds these effects, and as a result, the plastic constant of hot rolled material with a thickness of 1.6 mm is on the same level as that of 0.8 mm cold rolled material, and 0.8 mm hot rolled material is on the same level as ultra-thin 0.15 mm class cold rolled material.

Further, when the changes in rolling force are compared in the case of a 1% change in strip thickness, as an index of the change in the rolling force during thickness control, the change in rolling force is several times greater in hot rolling than in cold rolling. Moreover, the

Table 1 Thickness, shape and crown control functions

	Thickness control	Shape and crown control
Hard-ware	Hydraulic push down with MMC AC motor Inter-stand X-ray gauge	High response bender Pair cross Inter-stand crown meter
Setup control	Optimum draft schedule Rolling force model Forward slip model	Cross and bender setup model
Dynamic control	AG-AGC M-AGC FGC Tension control	Bending force control corre-sponding to rolling force Shape meter FB bender con-trol
Adaptive control	Flow stress learning Temperature learning	Crown learning Shape learning

MMC: Mill modulus control
AG-AGC: Absolute gauge AGC
M-AGC: Monitor AGC
FGC: Flying gauge Change

large changes in the rolling force do not simply get thickness control performance worse, but also cause a deterioration in the flatness of the strip due to changes in the elastic deformation of the rolls by the changes in rolling force. For this reason, it is necessary to give special consideration to the hot rolling facilities and control technologies when rolling the ultra-thin hot rolled strips.

2.2 Thickness Control Technology

Table 1 shows the thickness control technology and characteristics of the shape and crown control system at Chiba 3HOT. AGC (automatic gauge control) is an essential technology for obtaining advanced thickness accuracy. Although numerous AGC methods are available, the most generally used method is monitor AGC, which measures the thickness deviation at the delivery side of the hot finishing mill with a thickness meter, and controls the screwdown positions of several stands in the downstream section of the finishing train. However, when the feedback gain between multiple stands is not proper, roll gap control is concentrated in a particular stand, sometimes resulting in large changes in rolling force. In order to meet the requirements of rolling the ultra-thin hot rolled strips, which have an extremely large plastic constant, as mentioned above, Chiba 3HOT is equipped with thickness meters at all downstream finishing stands (F4, F5, F6 and F7). The thickness control system at 3HOT is capable of achieving the aimed thickness at all stands by minimizing the thickness deviation at the downstream stands based on the actual thickness at each stand, and adopting absolute gauge AGC even in the upstream stands, which are not equipped with thickness meters.[7] This thickness control system has made it possible to achieve high accuracy thickness control, in which thickness deviation control is not concentrated on a particular stand.

The development of endless rolling has realized stable rolling under constant tension over the entire length of the coil. However, because the tension is not applied to the head end of the first strip or the tail end of the last strip in the endless rolling sequence, the endless rolling includes a risk of the same type of threading trouble as in conventional rolling. For this reason, the top and bottom ends of the endless rolling sequence are rolled at the conventional minimum thickness of 1.2 mm, even in endless rolling of ultra-thin hot rolled strips, and the ultra-thin material ($t < 1.2$ mm) is rolled in the interval between the two ends (1.2 mm).

A thickness change from 1.2 mm to 0.9 mm while the strip is being passed requires a 25% change in the strip thickness. Accordingly to one report,[8] small thickness changes of approximately 10% have been carried out during strip passing in conventional hot rolling of thick materials. However, in flying gauge changes with ultra-thin hot rolled strips, it is necessary to make a large schedule change in thickness reduction without concentrating the schedule changes at some particular stand. Therefore, a flying gauge change system was developed, based on setup calculations, which sets the most suitable rolling schedule for the coils before and after the flying gauge change, and changes the roll gap positions and the roll velocities of all stands in accordance with those setup results.

In order to fully synchronize velocity changes due to mass flow balances and large roll gap changes, quick response hydraulic screwdown equipment and AC motors were adopted at all stands, providing the complete roll gap and roll speed control. Furthermore, the high response tension control by the distributed control was developed for rapid correction of mass flow error, thus establishing a technology for stably performing the large flying gauge changes in a short period on the order of 0.5 s.

2.3 Shape Control Technology

When hot rolled material is used as a substitute for cold rolled material, the flatness of the strip becomes extremely important as a product quality requirement. Maintaining satisfactory flatness in ultra-thin hot rolled strip is also extremely important for preventing pincher trouble when the tail end of the strip passes the finishing mill. In the hot rolling process for ultra-thin strips, flatness easily deteriorates due to the low stiffness of the strip. Moreover, in endless rolling, because rolling is performed continuously with a sequence of several conventional coils, there were also fears that the heat expansion (thermal crown) of the rolls would become excessive, deteriorating the flatness of the strip.

Table 1 shows an outline of the shape control system at Chiba 3HOT. To prevent shape changes, the cross angle and bender force are set in consideration of the secular change in the roll profile due to thermal crown and roll wear, and bender control is interlocked to changes in roll force. It has become possible to obtain good flatness from the leading end of the strip by applying shape feedback control, which controls the bender force at the final stand by means of a steepness defect meter behind No. 7 finishing stand, and crown and shape learning control using interstand crown meters and a steepness defect meter at the delivery side of the finishing mill.

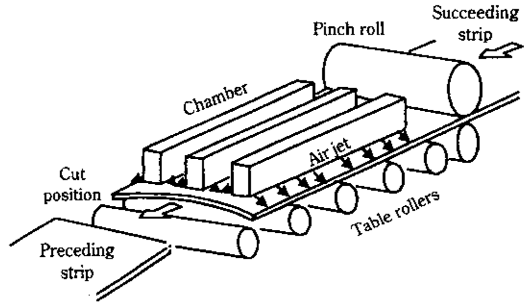


Fig. 2 Schematic diagram of floating threading device

2.4 High Speed Threading Technology in Front of Coiler on Hot Run Table

When hot rolling ultra-thin hot rolled material, the strip temperature easily drops, and it has therefore been necessary to roll at high speed in oder to secure a finishing delivery temperature (FDT) above to transformation temperature. Endless rolling solved the problem of high speed threading in the finishing rolling mills and on the finishing delivery table (hot run table). However, because the material is sheared into coil units for each order weight immediately before the coiler, it is necessary to guide the top end of the following material to the coiler correctly after shearing. A high speed threading device was developed for this purpose, as shown schematically in **Fig. 2**.[5] The device uses an upper guide equipped with an air chamber, which is installed above the table rollers. The strip is drawn up and floated by reducing the air pressure between the nozzles and strip, using air jets blown from the chamber. In addition to reducing the threading resistance of the strip by this drawing and floating action, the device also helps to realize stable threading by increasing the rigidity of the strip, which is achieved by positively floating the center of the strip to bend the strip in the width direction. Using this device, coiling of ultra-thin hot rolled strip has become possible.

3 Quality of Ultra-thin Hot Rolled Strip

As a result of the technical developments described above, it has become possible to produce ultra-thin hot rolled strips substantially exceeding the product size range of conventional hot strip coils. **Figure 3** shows the new available size range. The conventional minimum

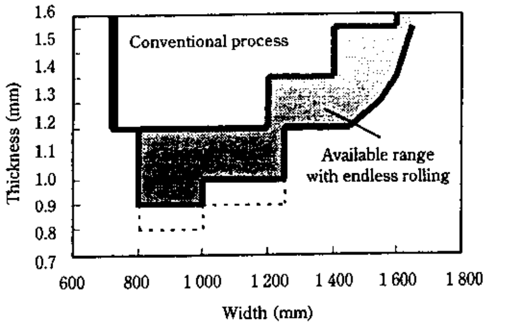


Fig. 3 Available size range

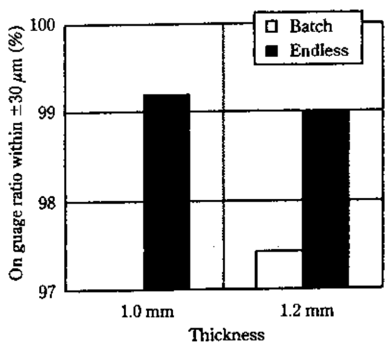


Fig. 5 On gauge ratio

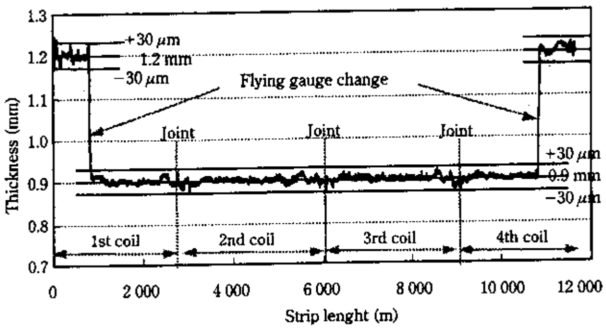


Fig. 4 Center thickness of ultra-thin hot strips (1.2→0.9→1.2 × 1 025 mm, 4 coil endless rolling)

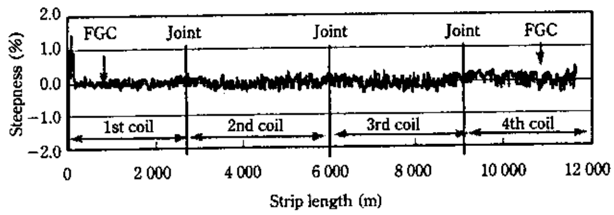


Fig. 6 Flatness of ultra-thin hot strips at delivery of finishing mills (1.2→0.9→1.2 × 1 025 mm, 4 coil endless rolling)

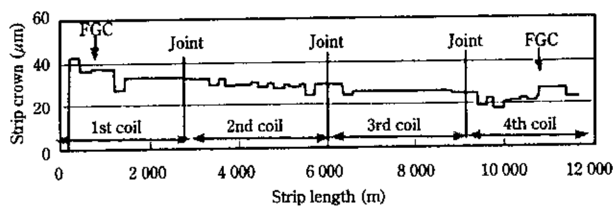


Fig. 7 Change of strip crown during endless rolling (1.2→0.9→1.2 × 1 025 mm, 4 coil endless rolling)

thickness of 1.2 mm has been expanded to 0.8 mm by applying endless rolling, and it has also become possible to roll thin and wide materials, such as 1.2 mm × 1 500 mm. Sales of ultra-thin hot rolled steel strip began in 1997 under the trade name RTHC (River thin thickness hot coil commercial grade). This chapter describes the dimensions, mechanical properties, and other quality characteristics of these new products.

3.1 Thickness Accuracy

Figure 4 shows a thickness chart when 0.9 mm material was rolled with a flying gauge change from 1.2 mm. In this example, the endless rolling sequence comprised four joined coils, and flying gauge changes were performed in the first and last coils in the sequence. It was possible to obtain a thickness accuracy within ±30 μm over the entire length of the sequence except at the top end of the first coil in endless rolling, and the flying gauge changes were carried out very quickly.

Figure 5 shows the on-gauge ratio within ±30 μm of 1.0 mm hot rolled strips produced by endless rolling in comparison with 1.2 m hot rolled strips produced by batch and endless rolling. In endless rolling, the strip thickness deviations which occurred in the non-stable parts at the top and tail of the strip were greatly reduced by endless rolling, and as a result, the on-gauge ratio exceeded 99% with both the 1.2 mm and 1.0 mm hot rolled strips. Moreover, the on-gauge ratio of the 1.0 material was even higher than that of the 1.2 mm material, showing that extremely good thickness accuracy can be achieved in ultra-thin hot rolled strips.

3.2 Crown and Flatness

Figure 6 shows the actual results of steepness as detected by the steepness meter at the delivery side of F7 stand. Although the top end of the first coil in endless rolling showed a sharp steepness of about 1%, this was quickly reduced to approximately 0.3% by shape feedback control, and thereafter, satisfactory flatness was maintained over the full length because a stable rolling condition was realized, with tension applied to the strip at all times. The trend in the strip crown in the longitudinal direction, at a position 25 mm from the strip edge, is shown in **Fig. 7**. Strip crown was gradually reduced in the coils comprising the endless rolling sequence due to the growth of thermal crown.

Figure 8 shows a comparison of the thickness profile

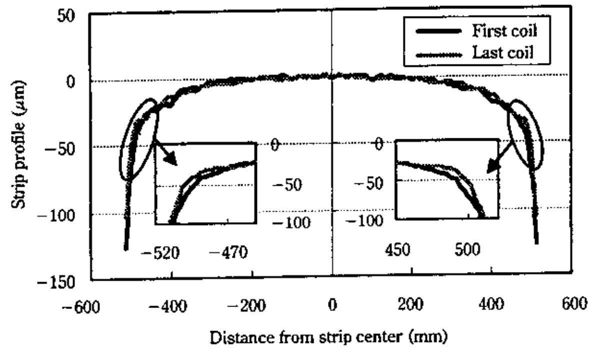


Fig. 8 Comparison of strip profile between first and last coils in one endless rolling set

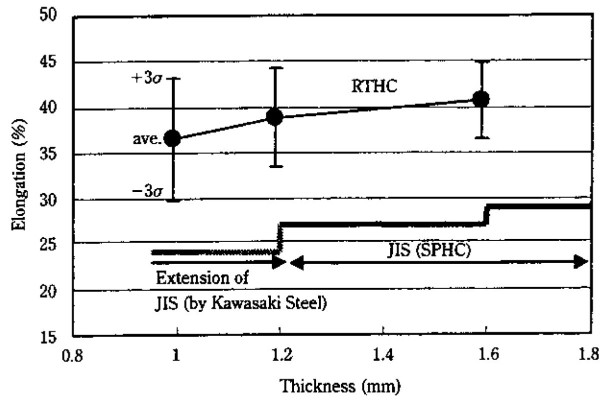


Fig. 10 Elongation of ultra-thin hot rolled strips

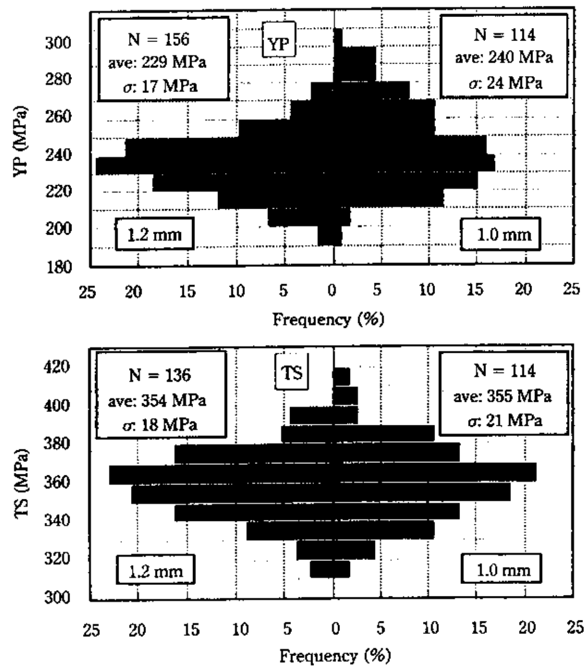


Fig. 9 Comparison of mechanical properties between 1.0 and 1.2 mm strip

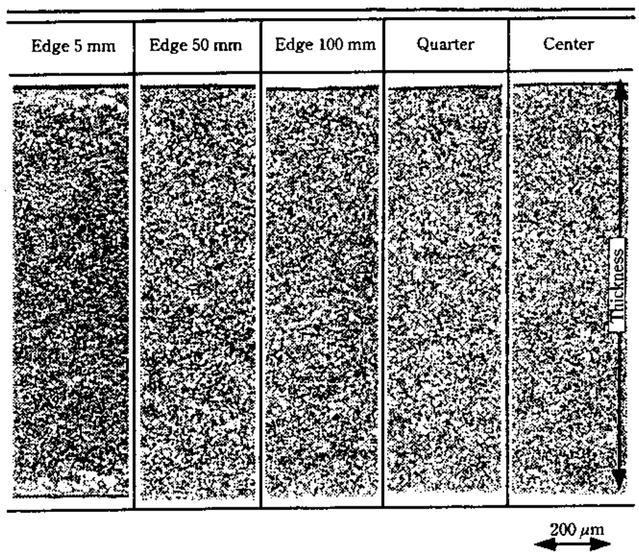


Photo 1 Micro structure of ultra-thin hot rolled strips

in the width direction of the first and last coils in the same endless rolling sequence. The profiles of both coils showed virtually no deviation, with a slight amount of difference being observed only at the edges. In spite of the effect of thermal crown, as shown in Fig.7, this was limited only to the edges, and the strip profile can be regarded as virtually the same as that of the endless rolling coils.

3.3 Mechanical Properties of Ultra-thin Hot Rolled Strips

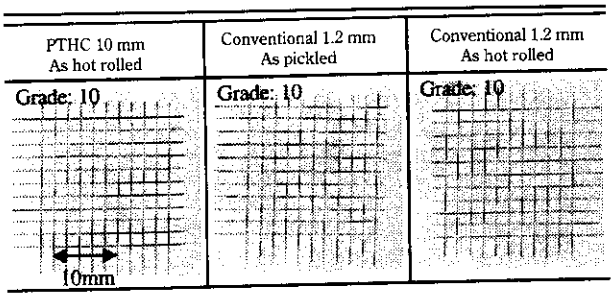
Figure 9 shows the results of a tensile test of ultra-thin hot rolled strips 1.0 mm in thickness in comparison with 1.2 mm hot rolled strips. The TS (tensile strength) and YP (yield point) of the 1.0 mm hot rolled strip were basically similar to those of the 1.2 mm material.

Figure 10 shows the elongations of ultra-thin hot rolled strips in comparison with the Japanese Industrial Standard. RTHC with a strip thickness of 1.0 mm shows a broadly superior elongation in comparison with the figures in the JIS standard, averaging 36.5%, and can be used in applications requiring deformation.

Photographs of the microstructure of 1.0 mm material, taken with an optical microscope, are shown in **Photo 1**. In cross sections in the width direction, the material displays a fine hot rolled structure to the top surface, and the abnormal grains which appear when the FDT is under the Ar_3 transformation temperature were not observed, confirming that it is possible to obtain strips with a normal microstructure.

3.4 Paintability of Ultra-thin Hot Rolled Strips

Photo 2 and **Table 2** show the results of a paintability



Iron Phosphate + Polyester Powder Coating
Grade 0 (Bad) – 10 (Good)

Photo 2 Result of paintability test (JIS K5400, wet paintability)

Table 2 Result of paintability test under various coating conditions

Coating	Material	RTHC 1.0 mm	SPHC 1.2 mm	SPHC 1.2 mm
	Surface condition	As hot rolled	As pickled	As hot rolled
	Scale thickness	5 μm	0	7 μm
	Phosphate treatment	Grades of paintability (JIS K5400) Dry/Wet, 0 (Bad) – 10 (Good)		
PP	ZP	10/10	10/10	10/10
EP	ZP	10/10	10/10	10/10
ME	ZP	8/8	8/8	6/6
ARE	ZP	8/8	10/10	8/6
PP	IP	10/10	10/10	10/10
EP	IP	10/10	10/10	10/10
ME	IP	8/8	10/8	4/4
ARE	IP	8/6	10/8	6/4

ZP: Zinc phosphate, IP: Iron phoshpate,
PP: Polyester powder, EP: Epoxy powder,
ME: Melamine enamel, ARE: Acryl resin enamel

test (JIS K5400) after painting. The 1.0 mm ultra-thin hot rolled strips showed the same paint properties as black and thick hot rolled strips and pickled hot coils, and therefore can be used in painted products.

4 Examples of Use of Ultra-thin Hot Rolled Strips

Kawasaki Steel's ultra-thin hot rolled strips had a major impact on the market as soon as they were delivered on a commercial basis, and have won a good reputation as the product of choice of many customers by meeting expectations for both quality and service.

Up to the present, the main uses have included round and square tubes (**Photo 3**), channels of various shapes, and light forming cut sheets for general use. These products are used in final applications such as purlins for roofs (**Photo 4**), fences (**Photo 5**), water pipes, furniture tubes (**Photo 6**), and other types of pipe.

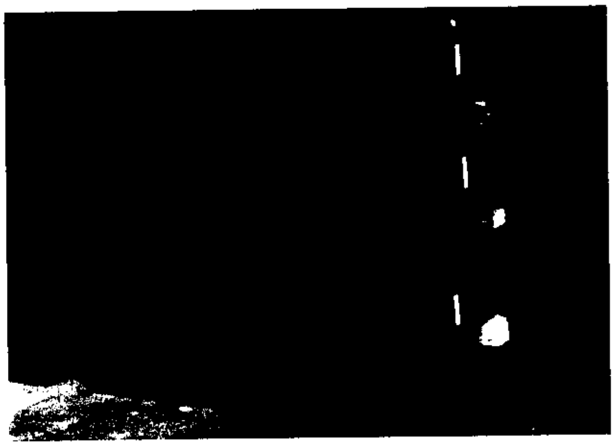


Photo 3 Stack of rectangular steel tubes made from ultra-thin hot rolled strips

Photo 4 Purlin (roll-formed light-gauge sections)

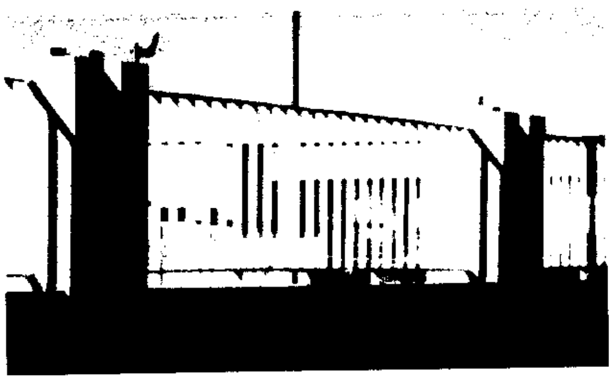


Photo 5 Fence of residential house (rectangular tubes)

To date, among the products in which cold rolled steel is competitive against hot rolled steel, ultra-thin hot rolled strip has been applied to parts which do not require severe forming, and production and sales have been increasing steadily. In the future, the company plans to expand the uses of these products to include more severe forming applications and higher tensile application.

5 Conclusion

The development of the endless rolling technology, together with an ultra thin-strip rolling technology which applies the endless rolling technology, has established a production technology for ultra-thin hot rolled strips with thicknesses of 1.0 mm, 0.9 mm, and 0.8 mm. Because it is possible to obtain excellent quality, including dimensional accuracy exceeding that of conventional hot rolled strips and mechanical properties on the same level as conventional material, these products are earning a good reputation. Ultra-thin hot rolled strip is a new product which responds to the trends of the times, including the need for weight reduction, energy saving, and CO_2 reduction, and is therefore expected to enjoying growing demand in the future.

Photo 6 Frame of bed (square tubes)

References

1) L. A. LeDuc-Lezama: *Iron & Steel Eng.*, (1997)4, 27–30
2) L. A. LeDuc-Lezama and J. M. Munoz Baca: *Iron & Steel Maker*, (1998)2, 25–31
3) H. Nikaido, S. Isoyama, N. Nomura, K. Hayashi, K. Morimoto, and H. Sakamoto: *Kawasaki Steel Giho*, **28**(1996)4, 224–230
4) F. Yanagishima: 7th Int. Conf. on Steel Rolling, (1998), 717–726
5) H. Nikaido: 169–170th. Nishiyama Memorial Technical Symp., (1998), 79–108
6) T. Kukizaki, H. Shiomi, H. Nikaido, and I. Hishinuma: SEAISI Taiwan Conf. (1999), Session 17-1
7) T. Imae, N. Nomura, and S. Miyoshi: *Kawasaki Steel Giho*, **28**(1996)4, 219–223
8) H. Kosuge, I. Tsuji, M. Nishio, K. Sekiguchi, H. Shibata, M. Noguchi, and M. Mishirogawa: The Proc. of the 36th. Jpn. Joint Conf. for the Tech. of Plasticity, (1985), 181–184