Compact Hot Strip Mill for High Quality Strip Production

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The use of unique technology such as tandem roughing stands, coil boxes, and PC mills on finishing stands of the minimill designed and built for TRICO has led to an ultracompact facility. Rough rolling, the uniform bar temperature in the coil box, and optimum descaling of the minimill produce steel strips with first-rate microstructure, surface quality, shape, and dimensions. The TRICO facility, with its excellent stable rolling of thin gauge strips, began producing 1.0 mm coil just five months after hot rolling started.

1. Introduction

Production of thin gauge strip 1.2 mm or less in thickness heretofore regarded as the domain of cold rolling technology is increasing being performed by hot strip mill facilities. On conventional hot strip mill lines, the main technical obstacles to hot rolling of thin gauge products are unstable rolling, in particular threading and coiling of the head end of the strip, as well as the non-uniformity of the microstructure over the whole length of the strip due to temperature drop at the tail. To overcome the obstacles, continuous rolling technology and a mini-mill directly connected to the continuous casting machine have been developed. Continuous rolling technology, in which a series of transfer bars are joined prior to rolling in the finishing mill, is currently in use at the Kawasaki Steel Corp., Chiba Works.

This paper introduces the compact mini-mill newly built for TRICO in the USA and provides a general explanation of the equipment, technology and operational results involved in producing high quality strip and thin gauge strip.

2. Line configuration and characteristics

The TRICO facility started operation in March 1997, seventeen months after the start-up of construction in 1995. The line configuration and the main specifications of the mill are shown in **Fig. 1** and **Table 1**.

Two continuous casting machines which can change product width on the fly are installed upstream of the hot strip mill, and they are operated synchronously and continuously with the hot strip mill. Although continuous casting machines usually cast 90 mm thick slabs, liquid core reduction from 90 mm to 70 mm is available to reduce the rolling load of the mill when processing thin gauge and hard material.

Slab is cast in the continuous casting machine and passes immediately into a roller hearth type tunnel furnace connected to the continuous casting machine, where it is heated uniformly to the temperature required for rolling. The furnace length is designed to include a buffer zone so that stoppage of mill operations (for roll changes, etc.) do not interfere with operation of the continuous casting.

A shifter type tunnel furnace is located downstream from the tunnel furnace to convey the slabs from either of the continuous casting machines to the mill. Two roughing mill stands (R1, R2) are arranged in tandem at the exit of the tunnel furnace and discharged slabs are reduced in thickness by a minimum of 17 mm and a maximum of 30 mm in a single pass.

Roughing mill stand roll gaps are adjusted by a long stroked hydraulic AGC cylinder. Descaling devices using high pressure water are installed on the entry side of R1 and R2 respectively. Furthermore, an edger is installed on the entry

Table 1 Main specifications of the hot strip mill

Item	Specification
Slab	
Thickness	90/ 70 mm
Width	940 to 1 650 mm
Roughing mill	
Motor power	R1: AC 6 800 kW R2: AC 8 000 kW
Rolling force	4 000 ton (max.)
Work roll diameter	R1: 1 350/ 1 250 mm R2: 1 150/ 1 050 mm
Back-up roll diameter	1 450/ 1 350 mm
Coil Box	
Operating thickness	17 to 30 mm
Maximum coiling speed	230 m/ min
Finishing mill	
Motor power	F1, F5: AC 6 000 kW F2 to F4: AC 7 500 kW
Rolling force	4 000 ton (max.)
Last stand speed	855 m/min (max.)
Work roll diameter	F1, F2: 825/ 735 mm F3 to F5: 680/ 580 mm
Back-up roll diameter	1 450/ 1 300 mm
Bending force	F1 to F4: 120 ton/ side F5: 150 ton/ side
Pair cross angle	0－1.2°(F1 to F4)

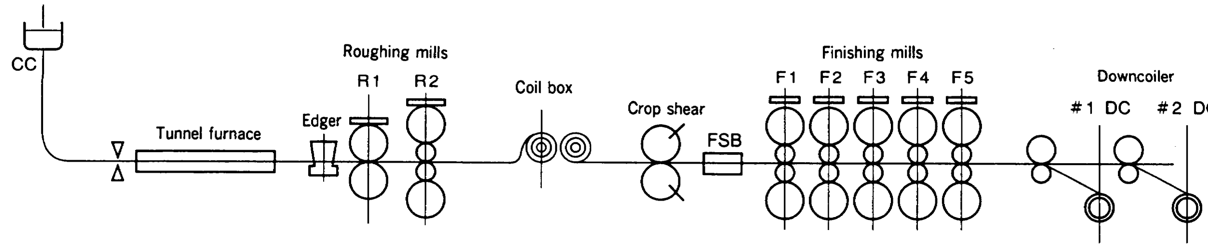

Fig. 1 Overall line configuration
Overall line configuration of the TRICO is shown.

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side of R1 to make width adjustments and compensate for width expansion which may be generated in the rolling process.

A coil box located downstream from the roughing mill coils bars (slabs) rolled in the roughing mill stands . The roughing mill stands and coil boxes operate simultaneously during coiling.

In conventional line configurations where no coil box is present, a delay table is required downstream from the roughing mill exit table in order to prevent rough bars rolled in the roughing mill from colliding with transfer bars waiting to be rolled in the finishing mill. A heat holding cover on the delay table is also required to prevent temperature drop at the tail of the transfer bar.

Furthermore, in some cases, to compensate for this temperature drop zoom rolling is required in the finishing mill. Naturally this leads to a larger line, increasing the number of the mill stands and requiring a larger drive motor.

By contrast, when the innovative coil box is incorporated into the configuration of the line, the length of the table between roughing mill stands and finishing mill stands can be significantly reduced. In addition, heat loss is drops and strip temperature is equalized from head to tail because the transfer bars are held in the coil box as a coil (i.e. coiled thereby minimizing the amount of heat which escapes during transfer). These features allow production of thin gauge strip free from both the threat of unstable rolling due to speed zooming in the finishing mill, and restriction of the specific coil weight. The coil box has two stations to allow for simultaneous coiling and uncoiling thereby improving productivity. (2-coil operation)

Uncoiled from the coil box, the head and tail ends of transfer bars are cut by a rotary drum type crop shear with differential speed cutting ability. Next high pressure descaling (Finishing Scale Breaker: FSB) removes scales which developed after roughing rolling, and the transfer bars are rolled to the specified strip thickness (1.0 mm to 15.9 mm) in the five (5) finishing mill stands. (F1 to F5)

All finishing mill stands are equipped with long stroked hydraulic AGC cylinders and strong benders to compensate for variation in strip thickness resulting from load variations during rolling, and for variations in strip profile due to growth of the thermal profile of the roll during operation of the line.

Furthermore, in F1 to F4, pair cross mills are applied to accurately control strip profile and shape as required for a wide range of rolling schedules.

An ORG (On Line Roll Grinder) is employed in both F4 and F5 to extend the roll change interval and permit schedule-free rolling.

The strip rolled in the finishing mill is conveyed by runout table to the two hydraulic downcoilers for coiling of the finished product.

The run out table is designed with a narrow pitch between its rollers so as to stabilize strip threading. Furthermore, a strip thickness gauge, a profile meter, a shape meter and a width gauge are installed on the runout table, and these are used for dynamic profile control, dynamic shape control and the strip thickness monitor AGC. Also a laminar flow type cooling system composed of 8 banks is installed on the runout table. QOC (Quick Open Control) is used on the downcoiler for wrapper roll position control so as to prevent marks from being made on the strip by the head end during coiling.

The TRICO mini mill profits not only from the construction and maintenance cost savings offered by its compact length, but also from: (1) optimum descaling, providing improved surface quality; (2) uniform and optimum microstructure over the whole length of the strip; (3) stable rolling of thin gauge product; and (4) high accuracy of product dimension and shape.

In the next section the technologies employed to achieve the superior quality strip described above, and the operational results are outlined.

3. Technologies employed and operational results

3.1 Optimum descaling

Descaling is performed in the appropriate location and sequence (R1 entrance, R2 entrance, FM entrance, between F1 and F2), as shown in **Fig. 2**.

Rough rolling is performed independently of the finish rolling, and therefore, the roughing mill can operate at a higher speed than if rough and finish rolling are performed synchronously, as in the conventional hot strip mill. As a result, both the growth of scale on the strip in the roughing mill and reduction in strip temperature due to descaling can be minimized.

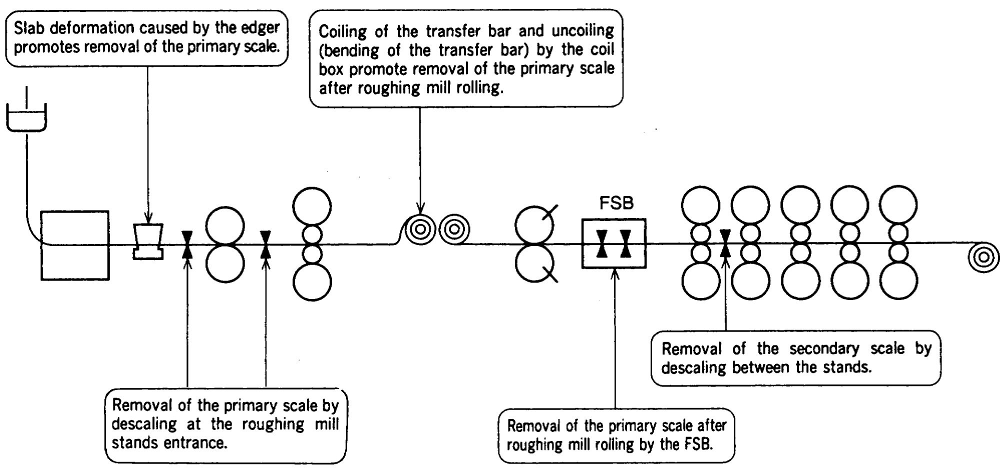


Fig. 2 Optimum descaling
The descaling layout, which has a high scale removal ability, prevention of scale growth, restricted reduction of temperature by descaling is shown.

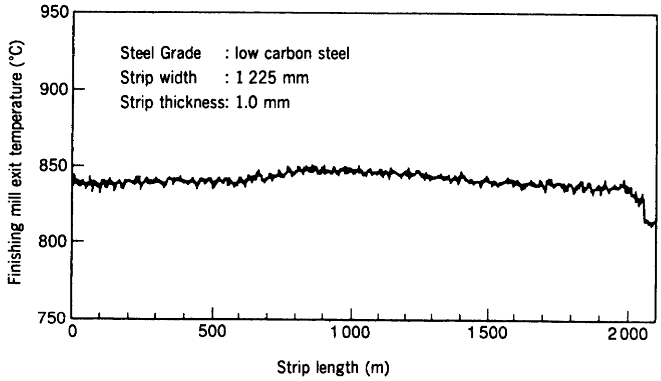


Fig. 3 Finishing mill exit temperature[1]

In addition to strip width adjustment capability and improved edge quality, the attached edger installed on the entry side of R1 also facilitates descaling. Moreover, coiling and uncoiling (bending of the bar) of the transfer bar in the coil box further assist in the descaling process at the FSB, and this optimized descaling process produces strip with excellent surface quality.

3.2 Uniform and optimum microstructures

As described above, after the slab has been rolled in the roughing mill, it is held as a coil in the coil box, where the temperature and recrystallized grain size are equalized precisely throughout the strip.

Furthermore, the reduction ratio for rough rolling of thin gauge product exceeds 50% at R1 and R2 and even in the case of thick gauge rolling, reduction ratio exceeds 45%. The high reduction capability of the roughing mill in turn further reduces the recrystallized grain size of the transfer bar.

After strip exits the finishing mill, constant required temperature is maintained throughout it's entire length as shown in **Fig. 3**. Consequently, microstructural and mechanical properties are equal to or better than those achieved with the conventional process.

Uniformity of microstructural and mechanical properties over the whole width of strip is achieved even in thin gauge rolling as shown in **Fig. 4**.

3.3 Stable thin gauge rolling

Rolling thin gauge product involves increased rolling force, and because the conventional mill does not have sufficient strip profile and shape control capabilities, the higher rolling force is compensated for by increasing the number of mill stands. When the number of stands increases however, the amount of heat lost between the stands increases as well, and line speed must be increased to prevent strip temperature from dropping.

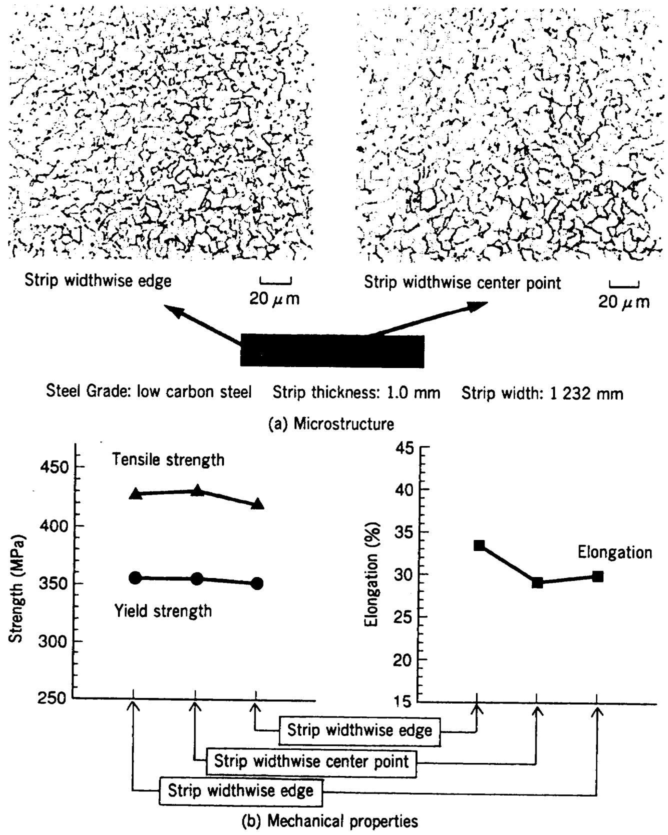


Fig. 4 Microstructure and mechanical properties of 1.0 mm thick strip
Uniformity of (a) Microstructure and (b) Mechanical properties over the whole width of strip is achieved even in thin gauge rolling (1.0 mm in thickness rolling)

This means high capacity stands are unavoidable.

To overcome this problem, Mitsubishi Pair Cross technology — affording superior strip profile and shape control capability — has been applied to the line at TRICO. Accordingly, hot rolling of thin gauge strip can be performed without increasing the number of stands and without enlarging stand capacity to compensate for increased line speed.

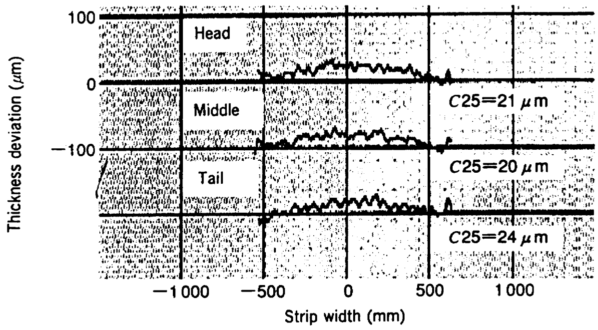
In actual operation, high reduction rolling — where thin strip 1.2 mm or less in thickness is rolled with a reduction rate of 60% — is regularly performed.

Table 2 shows a typical rolling schedule for 1.0 mm gauge product. In addition to the pair cross mills applied to the TRICO line, heavy benders have also been installed to control strip profile and shape while the bar is being rolled. Accordingly, as illustrated in **Fig.** 5(a) and (b), excellent profile and shape are achieved through the length of the strip, even when rolling

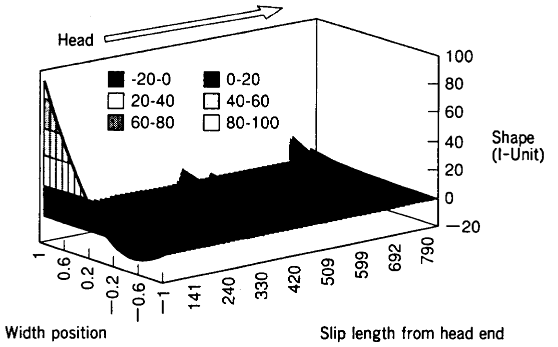
Table 2 Typical pass schedule for strip thickness 1.0 mm

Stand		R1	R2	F1	F2	F3	F4	F5
Reduction ratio	(%)	51	58	60	55	40	33	20
Rolling force	(t)	3 883	3 298	3 236	2 908	2 307	1 814	1 332
Mill speed	(m/min)	50	113	80	178	297	447	574
Strip thickness	(mm)	45.2	19.0	7.6	3.4	2.0	1.3	1.0
Pair cross angle	(°)			0.812	0.733	0.633	0.603	
Bending force	(t)			132	132	162	152	125

(Notes)
- Discharged slab temperature: 1 150℃
- Slab width: 1 248 mm
- Slab thickness: 91 mm
- Steel grade : low carbon steel



Steel Grade: low carbon steel Strip thickness: 1.0 mm
Strip width: 1 232 mm Target profile: 25 μm
(a) Strip profile



(b) Shape

Fig. 5 Strip profile and strip shape in 1.0 mm thin gauge rolling
This figure shows that by including the pair cross mill and heavy bender in the line configuration, excellent (a) strip profile and (b) strip shape can be obtained throughout the total length.

1.0 mm thin gauge product.

As noted above, the hot rolling equipment is directly connected to the continuous casting machine, and slab passes through a roller hearth type tunnel furnace where it is heated and kept at a uniform temperature from head to tail. As a result there is no development of slab marks on the strip surface. Additionally, uniform transfer bar temperature is maintained in the coil box so that as bar enters the finishing mill train its temperature is even from head to tail. In this way, rolling operations are extremely stable, even for thin gauge product, furthermore as shown in **Fig. 6**, strip thickness variation has been kept within 15 μm.

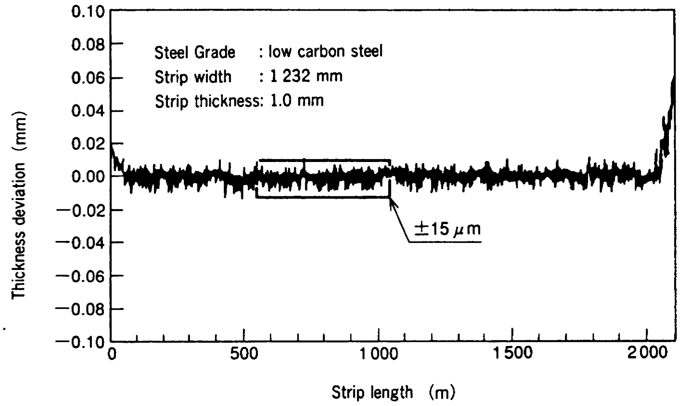


Fig. 6 Thickness behavior throughout strip length[1] in rolling of 1.0 mm thin gauge product
The hot thin gauge rolling is extremely stable and variation in target strip thickness minimal.

On the line at TRICO, the numerous advantages of minimill technology are complemented by specially developed computer software which allows for precision adjustments to the models and thereby provides constant fine turning and continuous improvement of operational performance. Consequently, within the short space of only 5 months after start up, the TRICO minimill progressed on to production of 1.0 mm gauge material.

4. Conclusion

The compact TRICO mill proves that production of excellent quality strip, which are equal to or better than those produced with the conventional process, is possible.

Notably, production of 1.0 mm thin gauge strip began only five months after start-up of operations, which clearly demonstrates the advantages this type of plant offers in terms of stable production of thin gauge strip.

A new compact minimill plant equipped with a tunnel furnace for the long slab in place of the coil box and featuring Mitsubishi pair cross technology is now under construction. In the future we are convinced that we can continue to make a valuable contribution to the diversification of thin gauge strip hot rolling mills.

Reference

(1) Minami, K. et al., Hot Rolling of Thin Gauge Strip at Trico Steel , STEEL ROLLING 1998 Paper, p.739