Development of Twin-Drum Strip Caster

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The strip casting process has attracted much attention as a new continuous casting method. Since 1985, Mitsubishi Heavy Industries, Ltd. and Nippon Steel Corporation have jointly developed a twin-drum strip caster for austenitic stainless steel and successfully completed it in 1993. Ten tons casting tests of the 800 mm and 1 300 mm wide prototype twin-drum strip caster have been conducted and have made it possible to establish stable casting technology and to confirm the high quality of cast strips. Moreover it was confirmed that the mechanical properties and the corrosion resistance of twin-drum cast products are equivalent or superior to conventional products.

1. Introduction

Today's steel industry is striving to improve its plants and equipment in order to reduce both energy and labor costs, while at the same time aiming at further reduction of production cost by omitting manufacturing processes. The strip casting process is a promising method to meet these requirements. Capable of near net shape casting and able to eliminate the hot rolling process, the strip casting process has been under active development throughout the world[(1)-(11)]. Moreover, the strip casting process featured by rapid solidification is expected to improve the properties of its products.

Mitsubishi Heavy Industries, Ltd. (MHI) and Nippon Steel Corporation have jointly developed a twin-drum strip caster (hereafter "strip caster") for austenitic stainless steel. This paper presents the results obtained from the 10-ton casting tests of the 800 mm or the 1 330 mm wide prototype strip caster. Our discussion focuses on stable casting technologies including automatic control systems and also on the properties of cast strips and cold-rolled products.

2. Development history

In the strip caster, molten steel is poured into a space enclosed by the drums and the side dams and solidified by heat extraction from the drum surfaces. At the point where the gap between the drums is smallest, the two solidified shells are pressed into a single cast strip. After fundamental tests using a small size test caster, MHI started casting tests in 1985 using a test caster with drums of 600 mm in diameter and 600 mm in width. The casting tests established the stable castability of 600 mm wide strips. As a result, MHI developed drums with less thermal deformation and side dams which press both edges of the drums. **Fig. 1** shows the 600 mm wide test caster in operation. After these tests and development, MHI tied up with Nippon Steel Corporation, and since then the two companies have jointly developed a strip caster for austenitic stainless steel. The history of the development is as follows:

STEP I : 1 200 mm dia. × 800 mm *W*, 1-ton scale pilot plant (1985-1988)

STEP II : 1 200 mm dia. × 800 mm *W*, 10-ton scale prototype plant (1989-1991)

STEP III : 1 200 mm dia. × 1 330 mm *W*, 10-ton scale prototype plant (1991-1993)

The joint development was successfully completed in 1993, establishing stable casting technologies for a 10-ton class caster.

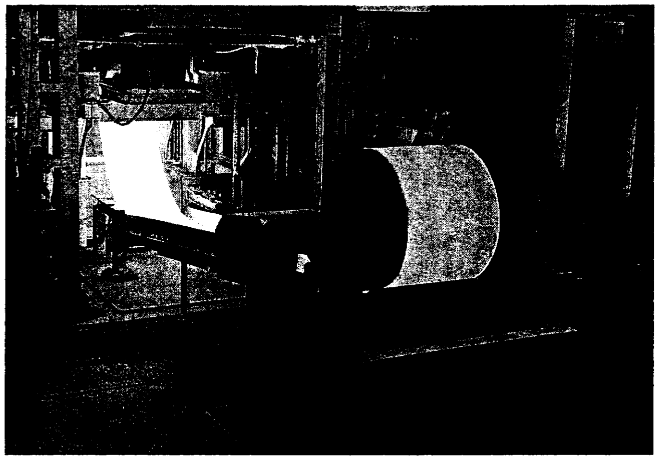

Fig. 1 Casting test using a 600 mm wide strip caster
The strip caster producing stainless steel strip.

3. Overview of 10-ton scale prototype strip caster

The 10-ton scale prototype strip caster was installed in Nippon Steel Corp. Hikari Works where the casting tests were carried out. **Fig. 2** shows a schematic view of the 10-ton scale strip caster. It is comprised of a ladle, a tundish, drums, side dams, pinch rolls, a tensioner and a coiler.

The drums, the core elements of the strip caster, need to meet the following requirements: little thermal deformation under heat of molten steel, no fatigue failure by repeated heating and cooling, and a stable thermal condition to solidify the molten steel. To satisfy these requirements, the drums have a three-layer structure consisting of stainless steel base, copper alloy sleeve, and nickel plating, and inside water cooling channels are equipped.

Molten steel leakage during casting is a serious problem of side dams. To prevent this problem, the thermal deformation was analyzed and the pressing method was improved.

The casting speed range was 20 to 130 m/min, and the corresponding range of cast strip thickness was 5.0 to 1.6 mm. The steel grade for casting tests was type 304 stainless steel.

4. Stable casting technologies

Because the strips produced by the strip caster are directly cold-rolled in the next process, its profile of width and longitudinal direction must be accurate. Various automatic

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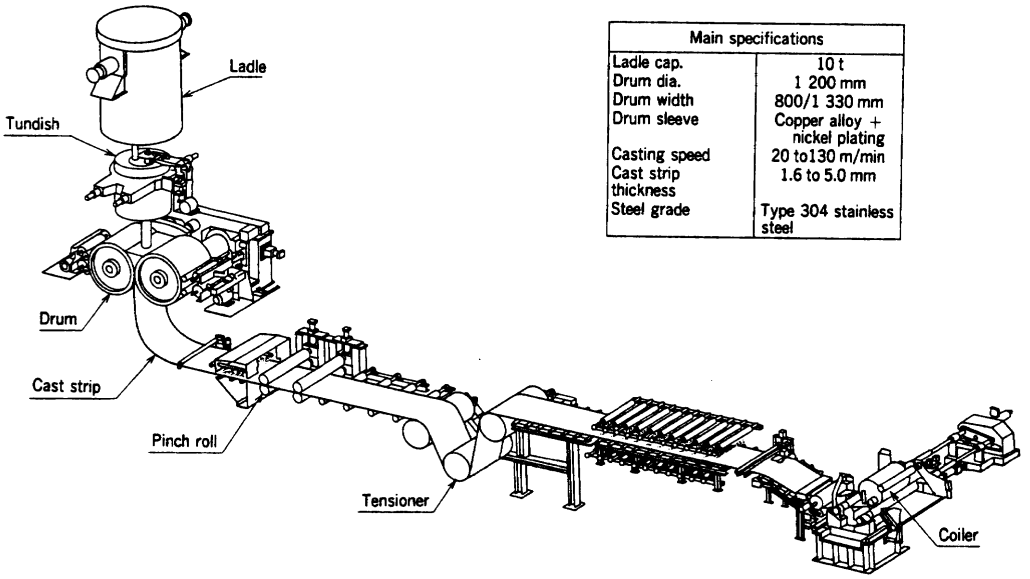

Main specifications	
Ladle cap.	10 t
Drum dia.	1 200 mm
Drum width	800/1 330 mm
Drum sleeve	Copper alloy + nickel plating
Casting speed	20 to130 m/min
Cast strip thickness	1.6 to 5.0 mm
Steel grade	Type 304 stainless steel

Fig. 2 Schematic view of 10-ton scale twin-drum strip caster
Schematic view of 10-ton scale twin-drum strip caster installed in Nippon Steel Corp. Hikari Works.

control systems were incorporated in the strip caster to ensure high standards of profiles and qualities of the cast strip and to establish stable casting technologies.

Fig. 3 shows the construction of the control system. The control system consists of automatic start logic, nozzle submerged depth control, liquid level control, cast strip thickness control, and line speed control. The strip caster starts operation using automatic start logic. The molten steel poured between the drums is maintained at a specified liquid level. During casting, a constant strip thickness is maintained by drum gap and drum force controls. In addition, the speeds of drums, pinch rolls, and coiler are also controlled to prevent an excessive force from being applied to the cast strip.

One of the twin drums is fixed. The other drum is driven at high response by the hydraulic servo system consisting of a hydraulic cylinder, servo valves, and position sensors. This makes it possible to adjust the drum gap accurately. The drum force acting on the cast strip is detected by a road cell connected to the fixed drum. The drum gap and drum force signals are put into thickness control system.

The thickness of the cast strip can be expressed by the following Eq. (1):

$$d=2Kt^n=2K\left(\frac{\pi R\theta}{180v}\right)^n \qquad (1)$$

where,

d : cast strip thickness (mm)
t : drum-steel contact time (min)
K : solidification coefficient (mm/min^n)
R : drum radius (mm)
θ : drum-steel contact angle (°)
v : drum speed (m/min)
n : constant

By substituting n=0.6 and K=29.7, the cast strip thickness obtained in the casting tests could be expressed using Eq. (1). To obtain a desired thickness using the equation, we can determine the ratio of the drum-steel contact angle θ (Fig. 3) to the drum speed v. Thus, drum-steel contact angle and drum speed are set at optimum values within their ranges.

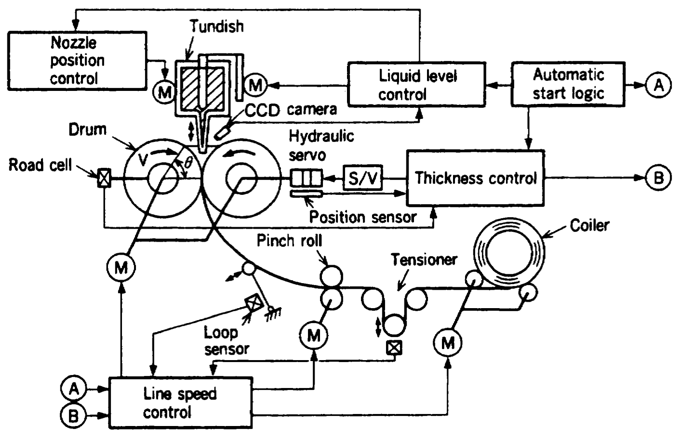

Fig. 3 Construction of control system
The construction of the control system incorporated in the strip caster.

Liquid level control is conducted by monitoring the drum-steel contact angle using a CCD camera and adjusting the molten steel flow rate with a tundish stopper. The accuracy of liquid level control in terms of drum-steel contact angle are within ±0.2 degrees (liquid level: ±1.6 mm). This accuracy is sufficient for stable casting and strip surface quality[10].

The strip caster is fitted with two automatic control systems of cast strip thickness: a constant-drum-force thickness control and a constant-drum-gap thickness control [12]. The constant-drum-force thickness control controls the drum force at high response and adjusts the drum speed to correct the resulting thickness deviation gently. The constant-drum-gap thickness control controls the drum gap at high response and adjusts the drum speed to correct the resulting drum force deviation gently. For further improvement of the strip thickness accuracy, the drum gap is corrected on the basis of the frame's deflection and thermal expansion as well as the drum's thermal expansion.

The surface quality of the cast strip is badly damaged by surface cracks. Surface cracks are caused by uneven solidification, which is due to surface ripples of molten steel in the

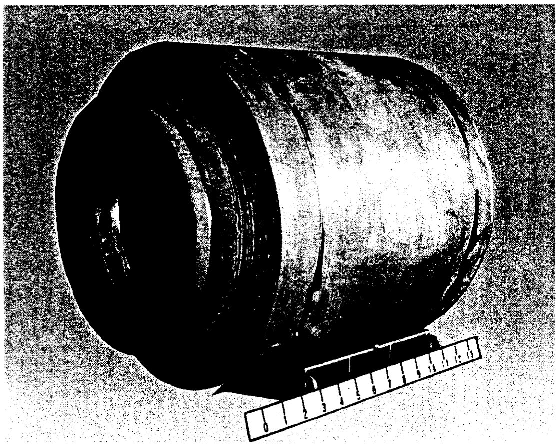

Fig. 4 Ten-ton coil of 1 330 mm wide cast strip
A 10-ton coil of 1 330 mm wide cast strip manufactured by the strip caster.

meniscus, dragging oxide films into the cast strips, and other phenomena. The strip caster has been enabled to produce cast strips without cracks by improving the method of pouring molten steel from the nozzle and controlling the atmosphere on the molten steel surface.

These stable casting technologies made it possible to produce 10-ton cast strip coils. **Fig. 4** shows a 10-ton coil of 1 330 mm wide cast strip.

5. Characteristics of cast strip

5.1 Solidification structure

Fig. 5 (a) shows a transverse cross section of the solidification structure. Columnar dendrites grow from the cast strip surfaces, and equiaxed crystals are formed at the center. The ratio of the standard deviation of columnar zone thickness to the mean thickness was measured at around 4%, indicating uniform growth of the solidified shells[13][14].

Furthermore, as shown in Fig. 5 (b), the cast strip exhibits less microsegregation than conventional slabs because of rapid solidification[15]. Fig. 5 (c) shows that cast strips produced by the strip caster have about only one-fifth as many non-metallic inclusions of 1 μm or larger as conventional products[16].

5.2 Cast strip profiles

5.2.1 Strip crown

To improve the accuracy of the cast strip crown, it is important to consider the drum shape. The drums are deformed under heat during contact with the molten steel. Using a model created to estimate the thermal deformation of the drums, thermal analysis was conducted to determine the initial profile of the drums. In addition, the stable drum structure, described above, was developed to control the strip crowns.

Fig. 6 (a) shows a measured distribution of cast strip crowns. The strip crowns are less than 90 μm and satisfy the target value.

5.2.2 Strip wedge

The strip wedge is controlled by means of gap control on the drive and work sides of the drums.

Fig. 6 (b) shows a measured distribution of strip wedges. The strip wedges are less than 60 μm and satisfy the target value.

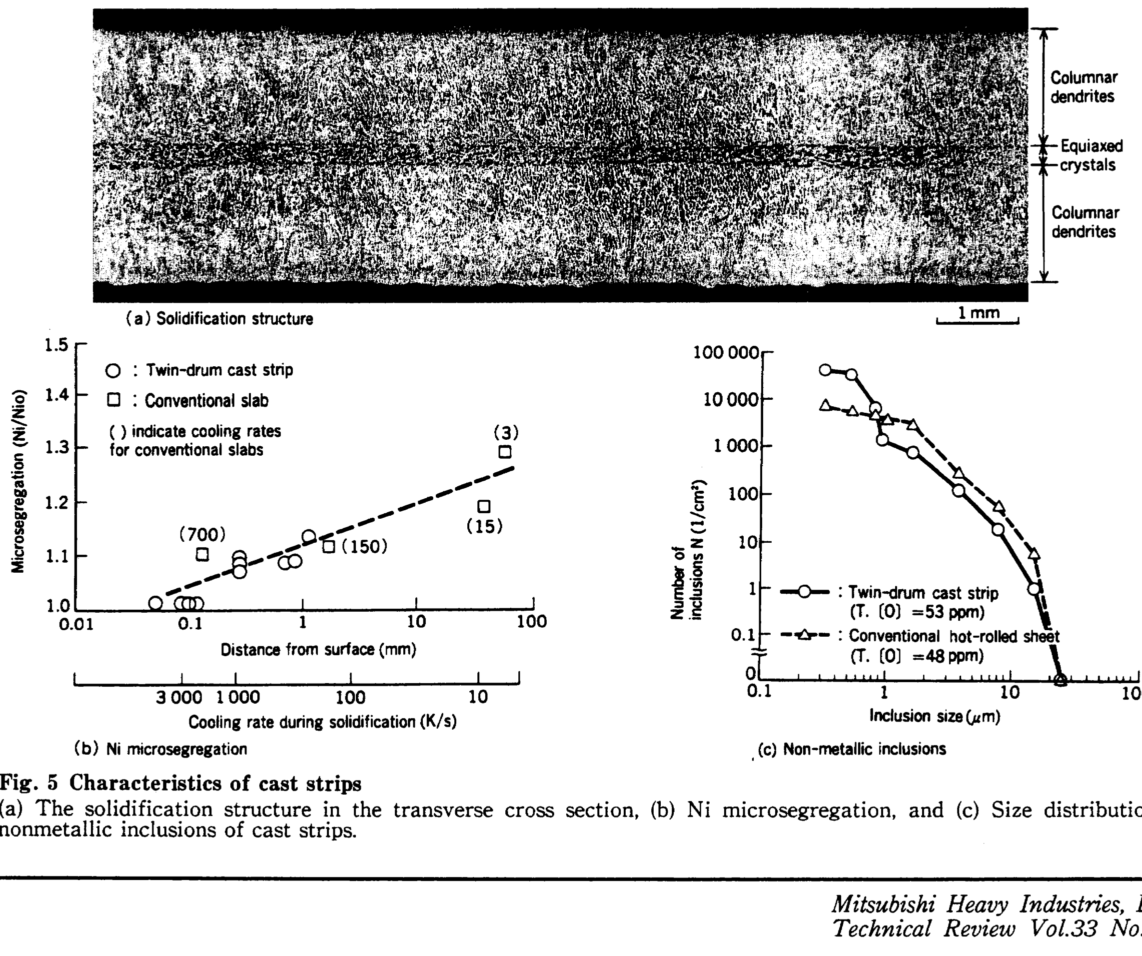

Fig. 5 Characteristics of cast strips
(a) The solidification structure in the transverse cross section, (b) Ni microsegregation, and (c) Size distributions of nonmetallic inclusions of cast strips.

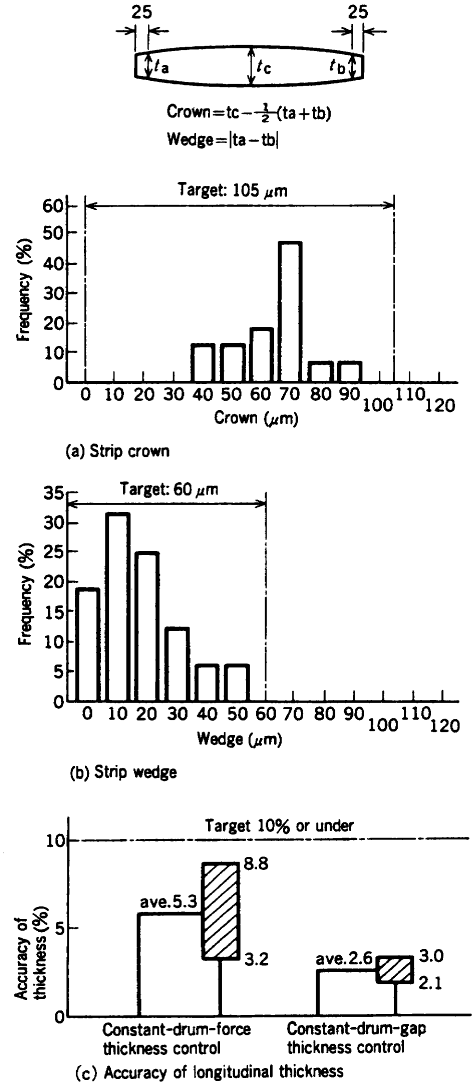

Fig. 6 Cast strip profiles
(a) Crown, (b) Wedge, and (c) Accuracy of longitudinal thickness of cast strips.

5.2.3 Accuracy of cast strip thickness in longitudinal direction

The accuracy of the longitudinal cast strip thickness was achieved by the thickness control systems described above. Fig. 6 (c) shows the variations of the thickness of cast strip produced using these thickness control systems. In both cases of thickness controls, the deviations are smaller than the target value of 10% : 8.8% (5.3% on average) under constant-drum-force thickness control and 3.0% (2.6% on average) under constant-drum-gap thickness control.

6. Properties of cold-rolled products

Type 304 stainless steel strips cast by the strip caster were directly cold-rolled and annealed to examine their properties. For comparison, slabs made by a conventional continuous casting machine were hot-rolled, annealed, cold-rolled, and annealed. The cold-rolled strips were finally finished by annealing-pickling and bright annealing. **Table 1** shows the mechanical properties and corrosion resistance of both products [17]. The twin-drum cast products exhibits much the same elongation and tensile strength as conventional products,

Table 1 Properties of cold-rolled products

Product \ Properties	Mechanical properties			Corrosion resistance
	Elongation (longitudinal) (%)	Tensile strength (N/mm^2)	Plane anisotropy (Δr)	Pitting potential* (V vs SCE) (V)
Twin-drum cast products	50.4	702	−0.24	0.38
Conventional products	50.8	702	−0.54	0.26

* (Conforming to JIS 0755)

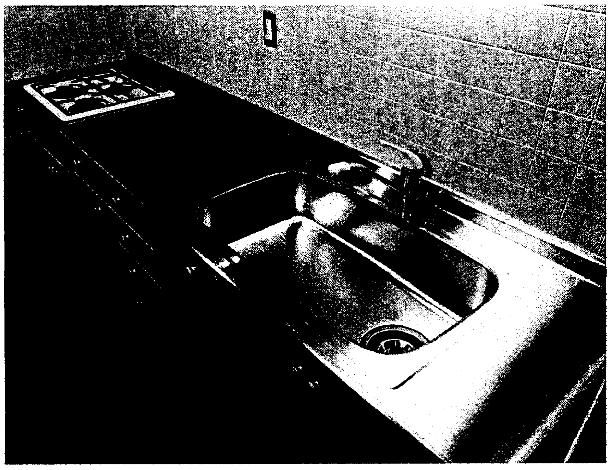

Fig. 7 Final product of cast strip
A final product of the cast strip (a sink).

and the smaller anisotropy. In pitting potential, an index of corrosion resistance, the twin-drum cast products show a higher value than the conventional product. **Fig. 7** shows a final product of the cast strip.

7. Conclusions

The following results were obtained from the 10-ton casting tests using 800 mm and 1 330 mm wide strip casters.

(1) Automatic control systems including liquid level control and thickness control were established to ensure stable casting.

(2) The cast strip profiles obtained (crown, wedge, longitudinal thickness accuracy) satisfied the target values.

(3) The cast strip is free from surface cracks and has an even solidification structure.

(4) The mechanical properties and corrosion resistance of twin-drum cast products of type 304 stainless steel are equivalent or superior to those of conventional products.

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