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Twin-torch Type Tundish Plasma Heater "NS-Plasma II" for Continuous Caster

Setsuo KITTAKA*[1] Shuji WAKIDA*[1]
Tadashi SATO*[1] Masayuki MIYASHITA*[1]

Abstract

In continuous casting, Nippon steel developed the twin type tundish plasma heater "NS-Plasma II"which has the high power output and long life. The features and effects of this system are outlined.

1. Introduction

The latest, rapid increase in the demands for high-grade steel materials requires expansion of the production capacity of existing continuous casters. On the other hand, in consideration of the loads on the global environment, it is necessary to urgently improve the energy efficiency and the production yield in steel production. In view of the above, a plasma heater for controlling the steel temperature in a tundish, used between a molten steel ladle and the mold of a continuous caster, is attracting attention as a measure to improve productivity, to save energy and to improve the production yields of high-grade steel materials.

As a response to these requirements, Nippon Steel Corporation developed a single-torch type tundish plasma heater, NS-Plasma I. The heater has been applied to a number of continuous casters and proved effective in stabilizing casting operations[1-3]. To better cope with the requirements in casters of large production capacities, Nippon Steel has developed a twin-torch type tundish plasma heater, NS-Plasma II. The new heater uses torches having a higher capacities and longer service lives, and is suitable for tundish hot recycling operation. This present paper explains the characteristics of NS-Plasma II.

2. Characteristics of Tundish Plasma Heater

The tundish plasma heater of Nippon Steel forms a plasma arc between the molten steel and a plasma torch provided above it, controls the output of the plasma arc, and thus optimally controls the temperature of steel in a tundish. High-temperature argon plasma is used as the heat source; the temperature at the center of the plasma arc is estimated at 10,000℃ or higher. Besides, because the molten steel is heated in a clean atmosphere of argon, an inert gas, it is easier by the process to protect it against oxidation, nitriding, carburizing and so forth than by other heating methods such as gas combustion heating[4].

3. Effects of Tundish Plasma Heating

As shown in **Fig. 1**, the heat of molten steel in a tundish is lost to the tundish refractory and by the radiation from the surface, and as a result, its temperature inevitably falls before a ladle change[5]. Plasma heating mitigates such a temperature fall to approximately one-third. **Fig. 2** shows the effects of tundish plasma heating. These effects are explained in more detail hereafter.

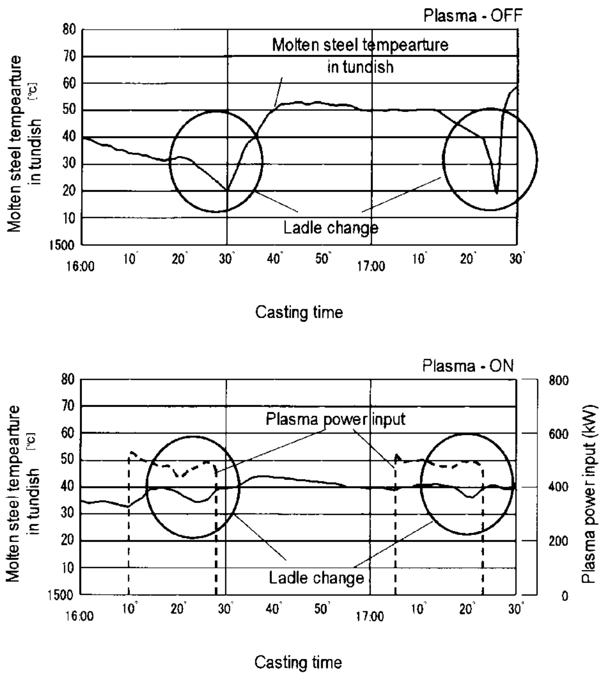


Fig. 1 Molten steel temperature control (example)

*[1] Steel Plant & Environmental Engineering Division

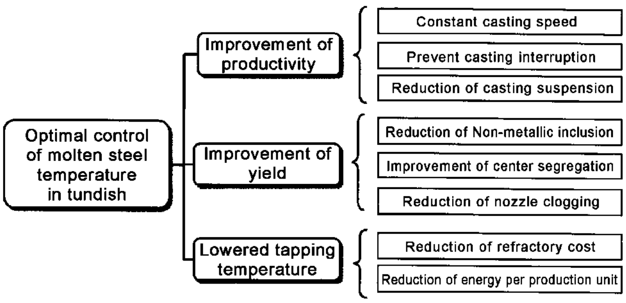


Fig. 2 Effects of plasma heating

3.1 Productivity improvement

The casting speed of a continuous caster is reduced when the molten steel temperature exceeds an optimum casting temperature range, especially at the beginning of casting and after a ladle change. The tundish plasma heating controls molten steel temperature and minimizes such decrease in casting speed. It also keeps the molten steel temperature within the optimum casting temperature range, prevents nozzle clogging, and thus reduces the suspension or interruption of casting operation[6]. Productivity increases as a result of these effects.

The single-torch tundish plasma heater that Nippon Steel supplied to Aichi Steel Corporation in 2002 is reported to have improved productivity by 5% by stabilizing the casting temperature and realizing constant-speed casting operation[7].

3.2 Yield improvement

As shown in **Fig. 3**, it is necessary to maintain the molten steel temperature within an optimum casting temperature range in order to secure high quality of cast steel, more specifically, to decrease both center segregation and non-metallic inclusions[8]. Center segregation and internal cracks are known to occur more easily when the molten steel temperature in a tundish exceeds an optimum temperature range. When the steel temperature is below the optimum casting temperature range, on the other hand, the immersion entry nozzle is likely to clog easily. Furthermore, non-metallic inclusions do not easily come up to the steel surface in the mold, and remain entrapped in the solidification shell, thereby causing surface defects (**Fig. 4**).

Tundish plasma heating controls the molten steel temperature in a tundish within an optimum range and prevents the occurrence of the above quality problems, and thus improves product yield.

3.3 Lower tapping temperature at steelmaking furnace

When a continuous caster is not equipped with a molten steel heater, the tapping temperature from a converter or electric furnace is controlled to a higher side in consideration of the temperature fall during casting. A tundish plasma heater prevents the fall of molten steel temperature in a tundish, which makes it possible to lower the tapping temperature. This leads to a decrease in the refractory costs of the steelmaking furnace and ladles and that of the energy input to the furnace as well.

Fig. 5 shows the advantages of the tundish plasma heating estimated in consideration of the above. According to calculations, the cost reduction that a twin-torch plasma tundish heater applied to a 1.2-Mt/y continuous caster enables is estimated at approximately ¥180/t. The productivity improvement of the caster accounts for 50% of the figure, the yield improvement for 30%, and the lower tapping temperature for 20%.

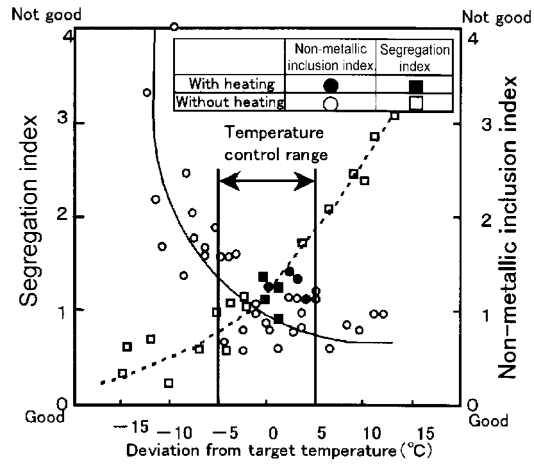


Fig. 3 Improved cast strand quality by the molten steel temperature control

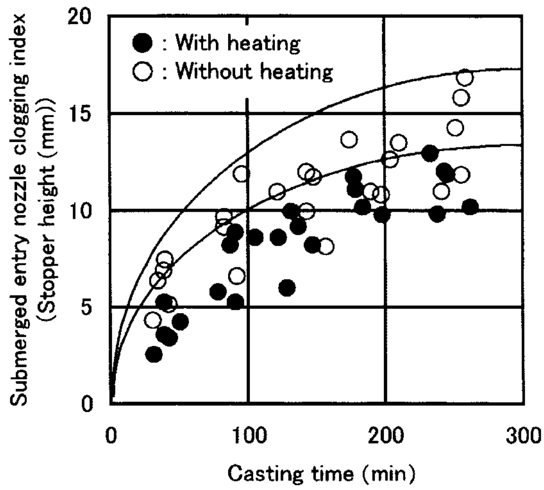


Fig. 4 Reduction of submerged entry nozzle clogging

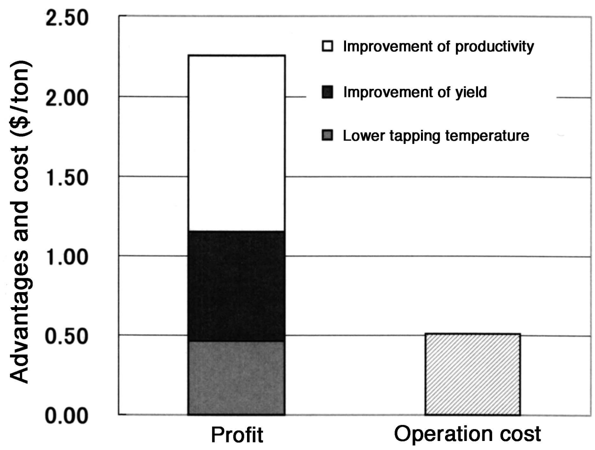


Fig. 5 Advantages of plasma heating

3.4 Application to new continuous casting processes

Twin-drum strip casting is one of new continuous casting processes. When casting temperature is too low, solid metal tends to form and accumulate at the lower part of a side dam of a twin-drum strip caster, often leading to operation problems[9]. Likewise, in a thin slab caster, low casting temperature is likely to cause insufficient melting of casting powder leading to other operation problems. Adequate control of molten steel temperature by a plasma heater is essential for preventing these operation problems[10].

4. Plasma Torch Specification Suitable for Every Type of Casters

Table 1 shows the characteristics of the torches used for Nippon Steel's tundish plasma heaters. There are two types of plasma torch arrangements, namely single-torch type and twin-torch type; a cathode torch or anode torch is used according to the type.

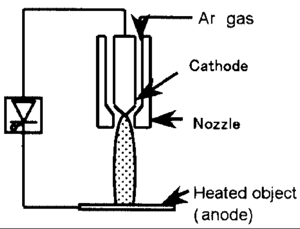
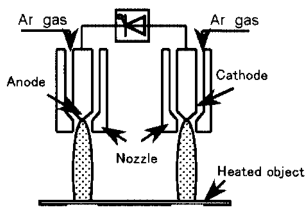
The single-torch type employs a cathode torch provided above the tundish, and a steel plate that acts as an anode embedded in the tundish refractory. A thermionic-cathode type torch that emits thermoelectrons is used for plasma discharge[11].

The twin-torch type uses two torches, a cathode torch and an anode torch, provided above the tundish. This type is characterized in that a plasma arc forms between each of the torches and the molten steel, thus the heating capacity is higher than that of a single-torch type, and that the anode steel plate is not required. Therefore, it is not necessary to modify the tundish to embed the anode plate in the refractory or provide cabling for it. In tundish hot recycling operation, if an anode steel plate is embedded in the tundish refractory for the single-torch type plasma heating, it is necessary to repair the anode plate within the tundish refractory recycling period. The twin-torch type is free from the anode repair work, and thus the maintainability of a tundish is greatly improved.

As shown in **Fig. 6**, a twin-torch type plasma heater has the anode and cathode torches that are arranged adjacent to each other. This torch arrangement allows a close side-by-side arrangement of power cables between a power supply unit and the torches. With this cable arrangement, the magnetic fields of the two cables cancel each other, and disturbances to electrical equipment such as noises for instrumentation are reduced.

Fig. 7 schematically shows the benefit of each type of tundish plasma heater used for casters of different production capacities. The single torch type, NS-Plasma I, is desirable for a small- to medium-capacity caster for billets and blooms, because the required heating capacity is relatively small. The equipment fits into a limited space because only one torch is employed. The argon consumption is small, and the number of torch consumables that require periodical change is also small, further enabling its ability to fit into limited space. On the other hand, the twin-torch type, NS-Plasma II, is suitable for a medium- to large-capacity caster such as a multi-strand or large-section bloom caster or a slab caster, because it outputs a large amount

Table 1 Comparison of the plasma heating type

	NS-Plasma I		NS-Plasma II	
Plasma torch type	Single torch		Twin torch	
	Cathode torch (anode: TD)		Cathode and anode torches	
	DC			
Composition				
Maintainability of torch	◯	External diameter: 1.1 (Separated nozzle)	◯	External diameter: 1.0
Power	◯	0.2 - 0.7MW Recommend: 0.5MW	◎	0.3 - 0.8MW
Heating efficiency	◯	60 - 70%	◯	60 - 70%
Plasma gas noise	◎	1.0 Low	◯	2.4 Slightly larger
Life of torch	◯	Cathode: 1.0 Anode: 1.0	◎	Cathode: 2.0 Anode: 2.0 Nozzle: 2.0
Electric noise	△	Regular	◯	Low
Modification	△	Heating chamber Anode plate in tundish	◯	Heating chamber
Maintainability of refractory in tundish	△	Anode plate has to be repaired in tundish Compativility with TD hot recycling: difficult	◯	Only general maintenance Adapted TD heat recycle: good
Equipment size	◎	Compact (because of one torch)	◯	Regular (because of two torches)

The figures without unit are indexed figures.
The following marks indicate evaluation: ◎ excellent, ◯ good, △ so-so.

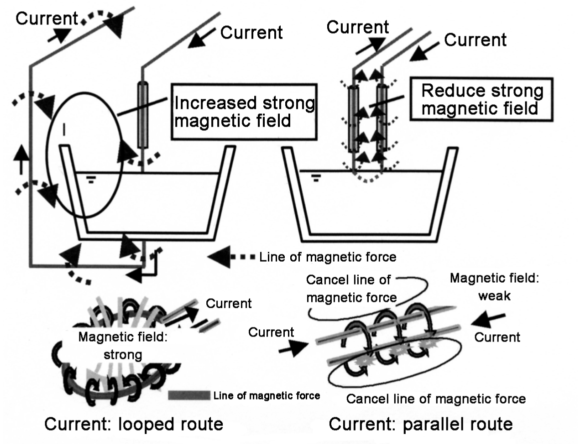


Fig. 6 Magnetic field generation characteristics of different torch arrangements

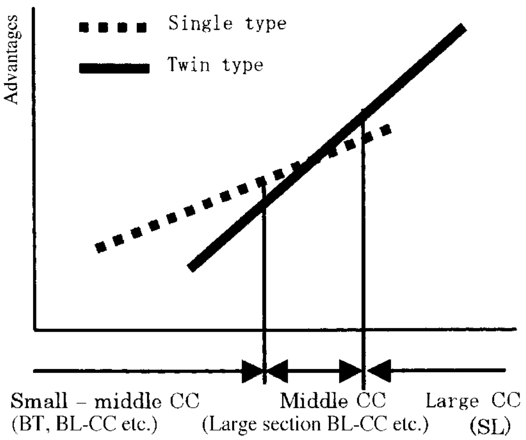


Fig. 7 Advantages by the plasma heating type

of heat with one power supply unit, and the service lives of the torches are long.

NS-Plasma II was developed exactly to meet the requirements of a medium- to large-capacity caster.

5. Characteristics of NS-Plasma II

Fig. 8 and **Table 2** show the equipment configuration and main specification, respectively, of NS-Plasma II. One of the torches acts as the cathode and the other as the anode. Since both the torches are mounted on a common drive unit, the mechanical configuration of NS-Plasma II is substantially the same as that of NS-Plasma I.

5.1 Longer torch life

In a plasma arc from a cathode to an anode, the ionized molecules of medium gas and dissociated electrons collide with each other repeatedly, and the energy released from the collisions produces high temperature. Here, the energy distribution in a plasma arc is higher near the anode than the cathode. As a consequence, the surface layer of the anode of the torch expands and protrudes under the high heat load, and the plasma arc from the molten steel tends to concentrate on the protruded portion, leading to the destruction of the anode. Nippon Steel studied an optimum shape of the anode surface through numerical analysis and laboratory tests, and developed

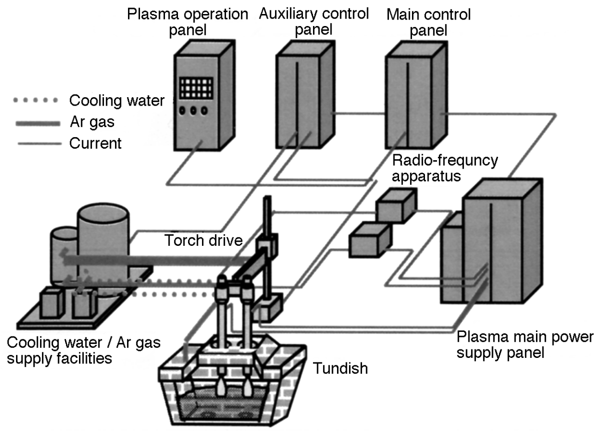


Fig. 8 Composition of NS-Plasma II

Table 2 Main specification of NS-Plasma II

Torches	Type	DC transferred plasma torch	
	Material	Cathode	Special tungsten alloy
		Anode	Special alloy
Current		DC 5,000A (max.)	
Voltage		Approx. 200 to 250 V (depending on atmosphere)	
Working medium		Ar	
Torch cooling water	Quality	Potable water	
	Specification	Conductivity < 50 μS/cm	
	Temperature	< 40℃	

a unique anode shape suitable for dispersing the heat load on the surface layer. Nippon Steel also developed an alloy material excellent in thermal resistivity for the anode. As a result, the service life of an anode increased approximately tenfold (virtually to the same level as that of a cathode) as shown in **Fig. 9**.

5.2 Measures for tundish hot recycling

To retrofit for a single-torch type tundish plasma heater (NS-Plasma I), it is necessary to embed an anode steel plate in the tundish refractory. This means that the refractory has to be modified, and power cabling such as a cable chain be provided at the time of the retrofit for each tundish, and when an anode plate has to be repaired, the refractory around it has to be repaired as well. This poses a problem in the tundish maintenance especially in tundish hot recycling operation. Nippon Steel newly developed an anode torch to replace the embedded anode plate, and mounted it together with the cathode torch on a common drive unit to form the twin-torch type plasma heater. The twin-torch type tundish plasma heater thus configured realizes a high power with compact equipment, makes the modification and repair of the tundish refractory unnecessary, and markedly improves the tundish maintainability in the tundish hot recycling operation.

6. Engineering Technologies

6.1 Tundish dam arrangement

The heating of molten steel with a plasma arc, as hot as 10,000℃ or higher, is done mainly through radiation, and the molten steel is

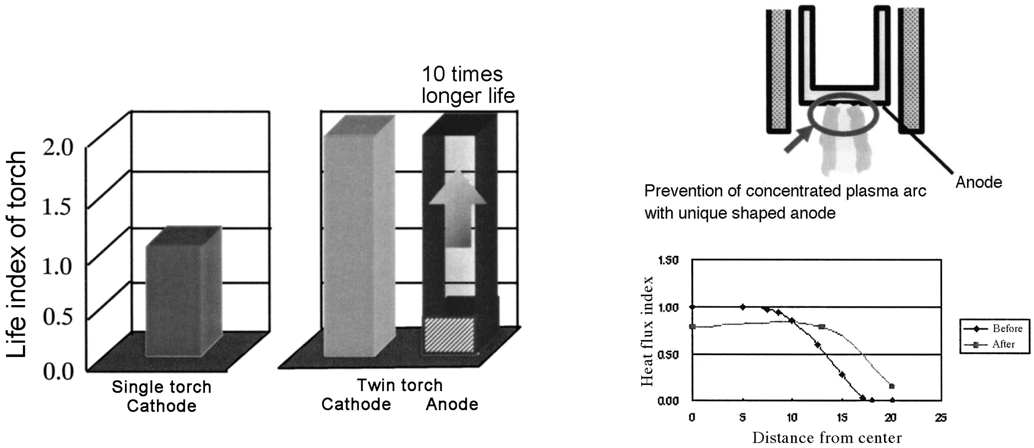


Fig. 9 Long life of anodic electrode

heated only at its surface. Therefore, when the molten steel flow in a tundish is inadequate, the steel is heated only locally, and the temperature of the steel flowing into the mold may not be raised sufficiently. Adequately arranging dams and weirs (partition walls) in the tundish as shown in **Fig. 10** solves this problem and raises the steel temperature stably and homogeneously.

Nippon Steel has analyzed the molten steel flow in a tundish, and developed a design technology to arrange dams and weirs appropriately in order to optimize the molten steel flow in consideration of the tundish shape and the torch position. The technology makes it possible to stably control the temperature of steel flowing into the mold.

6.2 Optimum torch layout

It is necessary to design the layout of a tundish plasma heater in consideration of the operability of related facilities on the operation floor such as a ladle car or ladle turret, tundish car and dummy bar storage car, and the interrelation between them. Nippon Steel determines the torch position so as to adequately raise the temperature of the steel flowing into the mold in consideration of the acceptable high temperature on the refractory of the heating chamber (see **Fig. 11**). Since the twin-torch tundish plasma heater has cathode and anode torches arranged adjacent to each other, special care is taken for the surface insulation and their arrangement for the purpose of prevention of the short circuiting between them. Accumulated operation and engineering technologies lead to the optimum design of the torch arrangement.

6.3 Design of heating chamber

The inner walls of the heating chamber are heated to high temperatures by the radiation of the plasma arc, and the damage to the refractory constitutes a serious problem to solve. In order to contain the inner wall temperature below the upper limit temperature of the refractory, a sufficient distance is secured between the plasma arcs and the inner walls based on temperature simulations (see Fig. 11).

When oxygen or nitrogen from outside mixes with the atmosphere in the heating chamber, it shortens the service lives of the torch and nozzle, and in addition, the plasma arc fails to form or it becomes unstable. Nippon Steel realizes stable operation of the equipment by filling the space enclosed by the heating chamber walls, weirs and the molten steel surface with argon gas, sealing the walls and the torch holes in the heating chamber, and thus keeping the atmosphere with high argon density in the heating chamber.

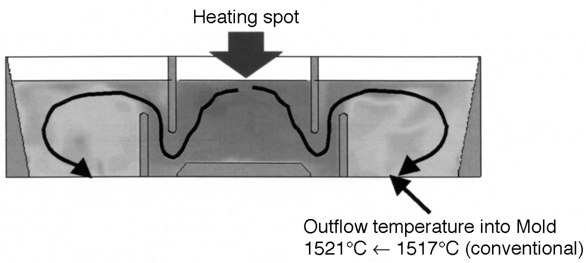


Fig. 10 Flow analysis of the moleten steel in tundish (example)

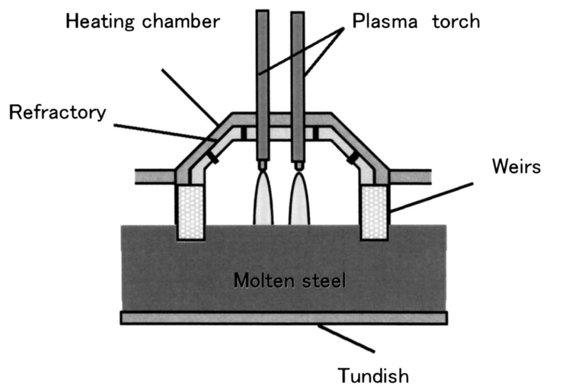


Fig. 11 Design of heating chamber

7. Summary

The twin-torch type tundish plasma heater, NS-Plasma II, developed by Nippon Steel has the following characteristics and advantages:

(1) When the temperature of steel supplied from a steelmaking furnace is inappropriate, the operation of a continuous caster is suspended or should adjust to meet the casting conditions required for the steel. The tundish plasma heater adequately controls the steel temperature in a tundish to compensate the temperature fluctuation, stabilizes casting operation, and thus significantly enhances the productivity of the caster.

(2) The heating of steel in a tundish decreases non-metallic inclusions and center segregation and prevents the clogging of an immersion entry nozzle to enhance the quality of cast steel, improve production yield and stabilize casting operation.
(3) The heating of steel in a tundish allows lower tapping temperatures from the steelmaking furnace, making it possible to reduce the refractory and energy costs in the steelmaking process.
(4) The anode plate embedded in the tundish refractory, indispensable for a single-torch type tundish plasma heater, is not required, and the maintainability of the tundish is improved. This simplifies the repair work of the tundish refractory necessary especially for the tundish hot recycling operation.
(5) The equipment design from the viewpoint of total engineering optimizes the arrangements of tundish dams and torches and the shape of the heating chamber, in consideration of the interrelation between them.
(6) The equipment comprises a heating system including newly developed high-power, long-life torches, and its layout is engineered for individual users based on the abundant operation experience of Nippon Steel.

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