Technology

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Development of Environmentally-conscious Steelmaking Process of Nagoya Works

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Abstract

Recent advances in the steelmaking technology at Nagoya Works are presented herein. For hot metal pretreatment, pre-desiliconization and the MURC process have been introduced to improve process efficiency and decrease slag volume. Ultra-low-sulfur steel refining capacity of RH degassing has been increased by decreasing brought-in sulfur, and sequential casting of 12 heats has been achieved. The heating capacity of the CC tundish plasma heater has been increased, which lowered the temperature of steel coming from the RH process. A new mold powder has been developed to prevent transverse cracks of high-tensile steel slabs. Measures have also been taken to reduce heat radiation loss from ladles.

1. Introduction

Decreasing greenhouse gas emission is targeted as a measure against global warming, and after the Kyoto Protocol in 1997, the Paris Agreement was adopted in 2015, and accordingly many countries have been making efforts to achieve the targets. Since Japan's steel industry accounts for roughly half of the greenhouse gas emission from the industrial sector of the country, the steelmakers are taking measures in close cooperation with each other. The activities have three objectives, namely eco-processes, eco-products, and eco-solutions, and in the field of steelmaking, eco-processes and eco-products are of particular importance.

Nagoya Works of Nippon Steel Corporation is located in an automobile manufacturing center, and have concentrated on the production of high-performance automotive steel sheets. In recent years, the manufacture of high-strength steel of tensile strength exceeding 1 000 MPa (all the units herein are metric) is required in response to increasing needs for automobile weight reduction to lower fuel consumption and CO_2 emission. In the production of difficult-to-produce high-tensile steel, which involves additional processes and is likely to have low yield, it is necessary to take effective measures against the increase in energy consumption and higher costs; such measures include further purification of steel and prevention of slab cracks. This report describes such technical developments and improvements in the steelmaking process of Nagoya Works over the last few years.

2. Measures for Efficiency Improvement of Hot Metal Pretreatment

2.1 Efficiency improvement of dephosphorization[1)]

Aiming mainly at reducing slag generation, technical development concentrated on raising the efficiency of hot metal pretreatment by using converters. In our previous paper,[2)] it is reported that an exclusive process for desulfurizing hot metal was newly established to separate desulfurization from dephosphorization, and the efficiency of the desulfurization has been improved. As an operational improvement of the latter, the oxygen blowing rate was increased in the early stage of the treatment to improve the process efficiency, especially when the silicon concentration in hot metal was high. By this, high process efficiency has been attained even with high initial silicon content.

On the other hand, as a result of the quality deterioration of iron ore, the silicon concentration in hot metal has increased. Especially when it exceeds 0.6 mass%, the dephosphorization rate falls inevitably, and in addition, slopping (overflow of slag and hot metal) occurs in the dephosphorizing converter, which often leads to interruption of the blowing and other operation problems. In consideration of the above, to lower the silicon content of hot metal before dephosphorization, a facility for desiliconizing hot metal in a torpedo

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car (hereinafter TPC in short) was built in 2018 (see **Fig. 1**). For this process, a system for injecting a desiliconizing flux was added to an existing desulfurization station equipped with a system for injecting the flux into a TPC, and the facility for deslagging from the TPC was expanded.

Soon after its start-up, the operation was often interrupted owing to slag foaming and burning of bag filters due to hot exhaust gas. However, appropriate measures were taken to address these problems, which has resulted in the achievement of the initial target of lowering the silicon content by 0.2 mass% on average. Against the slag foaming, the following measures were taken. It is obvious from **Fig. 2** that the interruption of the processing due to slag foaming occurred more frequently when there was little slag on the surface of the metal bath before the processing. The reason was presumably that the slag viscosity increased and the forming index[3] increased as a result of an extremely high SiO_2 concentration as seen in **Fig. 3**[4]. By blowing CaO into the hot metal in TPC the slag foaming has been controlled, and the process interruption has significantly decreased.

As for the hot exhaust gas, the gas was cooled by a water mist. These measures have resulted in an increase in the treatment ratio to a target of 52% as seen in **Fig. 4**.

2.2 Introduction of MURC process[5, 6]

The refining process of the Steelmaking Plant of Nagoya Works consists of three hot metal pretreatment converters (one of which is exclusively for desulfurization), three decarburizing converters, and secondary refining facilities. Because the capacity of the latter converters was greater than that of the former, hot metal without pretreatment was sometimes directly transported to the latter decarburizing converter, and was desiliconized and dephosphorized. This direct feed treatment of hot metal accounted for roughly 15% of the latter's capacity. In consideration of this situation, a modification to enable intermediate deslagging from the decarburizing converters was introduced, and the multi-refining converter (MURC) process was applied. At that time, the cycle time of the slag pans was the bottleneck of the process. Therefore, the air cooling time of the slag of dephosphorization (blow 1 of the MURC process) was optimized, and the handling of slag pans was also improved. As a result, it became possible to attain a target MURC application ratio of 10% (see **Fig. 5**, where BOF means converter).

3. Improvement of Refining of Ultra-low-sulfur Steel[7]

To meet the increasing demand for higher sour resistance and low-temperature toughness, the desulfurization process was improved more effectively and efficiently to enable the supply of a greater amount of ultra-low-sulfur steel. This increased the number of sequential castings to 9 through 12 heats.

To decrease the sulfur content of hot metal, the hot metal desulfurizing capacity was increased as previously reported.[2, 8] Since the

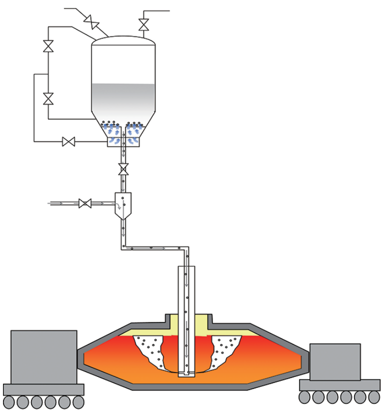

Fig. 1 Schematic illustration of TPC desiliconization

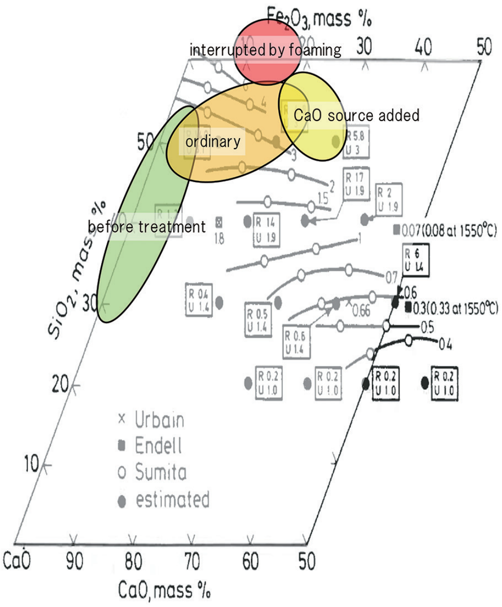

Fig. 3 Change in slag composition before and after treatment, and viscosity contours of $CaO-SiO_2-Fe_2O_3$[4] system

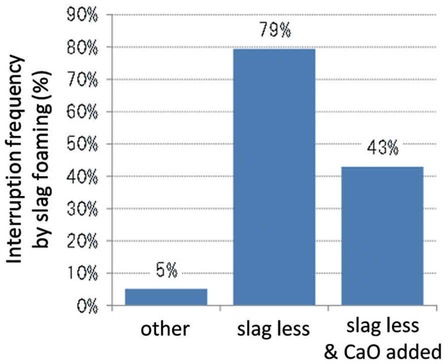

Fig. 2 Interruption of desiliconization processing

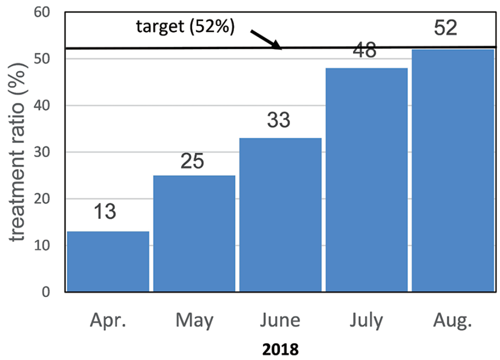

Fig. 4 Trend of TPC desiliconization treatment ratio

process time was shortened, the bottleneck in the supply of low-sulfur hot metal was relieved, and sequential casting of nine consecutive heats of ultra-low-sulfur steel was achieved. To achieve 12 consecutive heats, however, it was necessary to take further measures against the erosion of refractories of the RH degassers, especially that of the snorkels, by the desulfurizing flux. The deslagging after hot metal desulfurization in ladles was carried out completely as well as cleaning of the decarburizing furnaces to minimize sulfur pickup (see **Fig. 6**). As a consequence, the load of desulfurization treatment in the RH degassers and the amount of blown-in flux were decreased, and sequential continuous casting of 12 consecutive heats has been achieved (see **Fig. 7**).

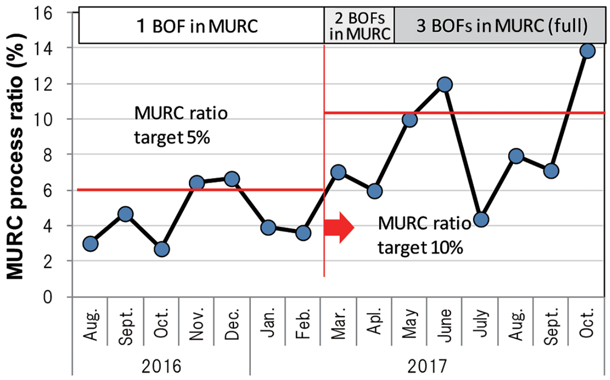

Fig. 5 Change in MURC process application ratio

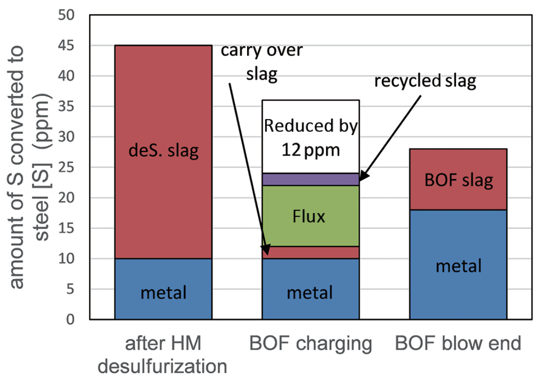

Fig. 6 Sulfur balance after improvement

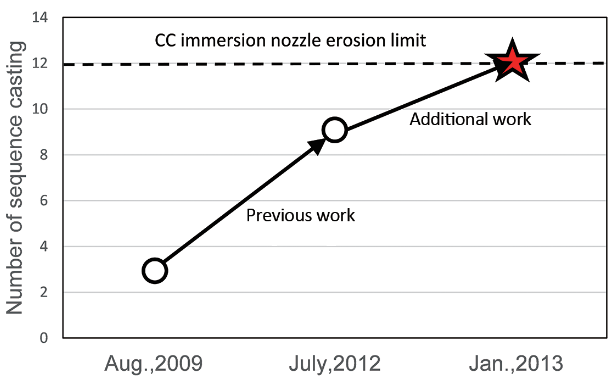

Fig. 7 Change in number of sequential casting

4. Development of High-quality Casting Technology

4.1 Efficiency improvement and operation stabilization of tundish plasma heater[9)]

The No. 1 Continuous Caster (No. 1 CC in short) of Nagoya Works produces slabs of medium carbon steel for high-strength thin sheets and those for heavy plates. The lower level of molten steel in the tundish at the joints between different steel grades in sequential casting is controlled, and the immersion nozzles are also replaced during the casting. These operations cause a drop in the temperature of molten steel, which is a serious problem for stable casting. Therefore, the temperature of molten steel was controlled by using a tundish plasma heater. However, after the machine length of the caster was extended to increase its production capacity, the capacity of the plasma heater was found insufficient. To solve the problem, the single-torch plasma heater was modified into a twin-torch heater (2 × 1.1 MW) in 2011, and measures were taken to improve the ignition success rate and extend the service life of the facility. **Figure 8** shows the configuration of the plasma heater after the modification.

The main improvements were as follows:

1) Prevention of misfire by improving the torch lifting sequence after ignition.
2) Stabilization of discharge by purging of argon in the heating chamber and preventing air intrusion.
3) Improvement of heat transfer efficiency by optimizing the molten steel flow in the tundish with a dam designed in consideration of the relationship between the steel flow rate and heating efficiency.

These improvements have led to lowering the temperature of the molten steel after the secondary refining (see **Fig. 9**).

4.2 Prevention of transverse cracks of high-tensile steel slabs by improving mold powder[10)]

Automobile weight reduction is required to improve the fuel efficiency, and to this end, increasingly higher strength is required for the steel sheets for automobile use. Nagoya Works has diligently endeavored to produce such difficult-to-produce high-tensile steel in as simple a manner as possible. Measures were required especially for the steel grades susceptible to slab defects, in particular transverse cracks, leading to high yield loss (such steel grades being hereafter referred to as “high-tensile steel A”).

Figure 10 shows the relationship between temperature and the

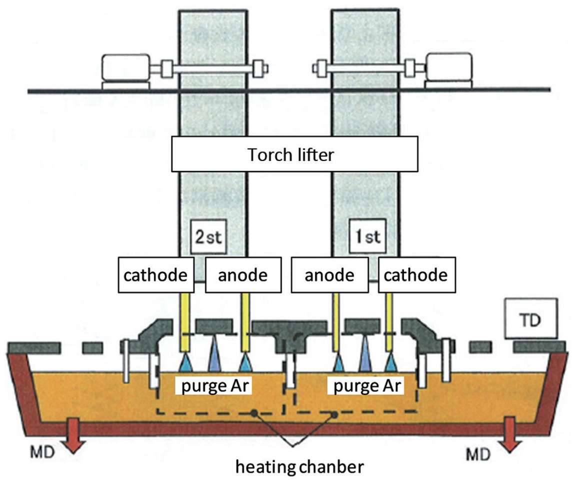

Fig. 8 Schematic view of plasma heater (twin torch system)

reduction in area in the hot tensile test of the high-tensile steel A; the tensile temperature to improve the hot ductility was found to be as high as over 1000°C. **Figure 11** shows a cross section of a transverse crack. It was found that the cracks occurred at the positions of oscillation marks (referred to as OSM in figures).

It is considered that the transverse cracks are due to the poor hot ductility of steel, in addition to the hypo-peritectic steel. The cause-and-effect map of crack of high-tensile steel A is described in **Fig. 12**, and the following approaches are considered to be effective in improving the transverse cracks of the high-tensile steel A: (1) unbending the slab in higher temperature of good hot ductility, (2) shallowing the depth of the oscillation marks, and (3) reducing the friction between the solidification shell and the mold. However, the approach (1) is not necessarily practical because the hot ductility of this steel is very poor, and it is very difficult to maintain the surface temperature of slab of more than about 1000°C during the unbending of slab. Therefore, the depth of oscillation marks, which acted as the starting points of the cracks, was targeted, and the approaches (2) and (3) were taken by changing the mold powder. The newly developed mold powder has the following properties: (a) lower crystallization temperature of cuspidine in the powder, (b) higher solidification point of the powder to cool the steel shell mildly in the mold, and (c) lower powder viscosity to reduce the friction between the mold and the steel shell by enhancing the influx into the gap.

Figure 13 shows the number and depth of transverse cracks. Utilizing the newly developed mold power has improved the cracks significantly, which results in a raise in yield as shown in **Fig. 14**.

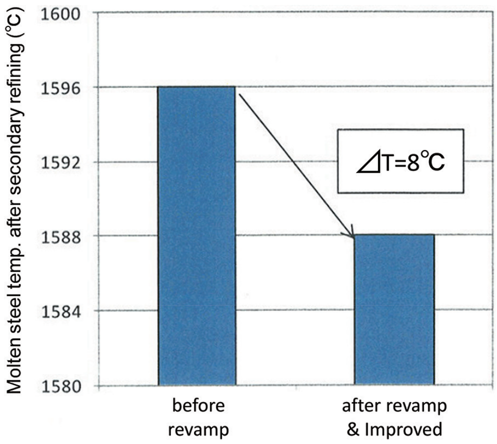

Fig. 9 Effect of plasma heater revamp on steel temperature after secondary refining

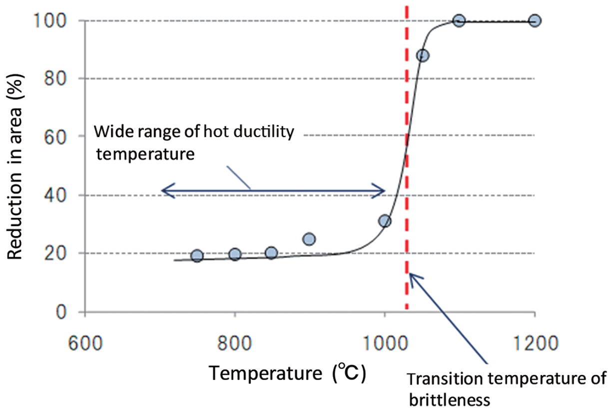

Fig. 10 Effect of temperature on hot ductility of high-tensile steel A

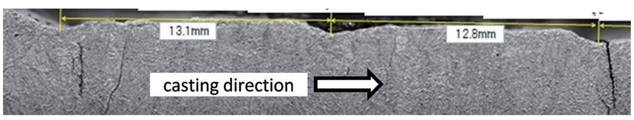

Fig. 11 Cross section of transverse crack

5. Decreasing Heat Radiation Loss [11, 12]

The following three measures were carried out to reduce heat radiation loss.

1) Reduction of heat radiation loss from empty ladles after casting — use of lids

Empty ladles after the continuous casting were covered with lids to minimize heat loss. At the time of deslagging after the casting, however, the lid is removed for maintenance reasons, and the ladle is often left without the lid until it receives molten steel of the next heat, and the heat loss increases when the waiting time is long. As a countermeasure, new equipment for putting lids on empty ladles was installed, and it became possible to lower the molten steel temperature after the secondary refining by 1.4°C. To improve the prediction accuracy of steel temperature drop, a model for estimating heat storage in the ladle is being formulated.

2) Life extension of tundish plasma heater for No. 2 CC

The steel temperature after the secondary refining has been lowered by 5°C by measures such as improvement of the torch life by optimizing the plasma application conditions, etc.

3) Minimizing the amount of molten steel in tundish at joints between different steel grades at sequential casting and effective use of plasma heater

To minimize the joints between different steel grades of No. 1 CC, which casts many steel grades in small lots, the tundish plasma heater shown in Fig. 8 was utilized effectively, and the molten steel

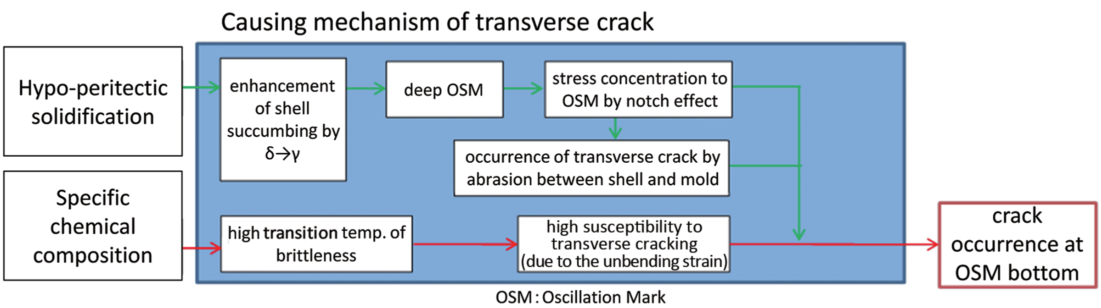

Fig. 12 Cause-and-effect map of cracks of high-tensile steel A

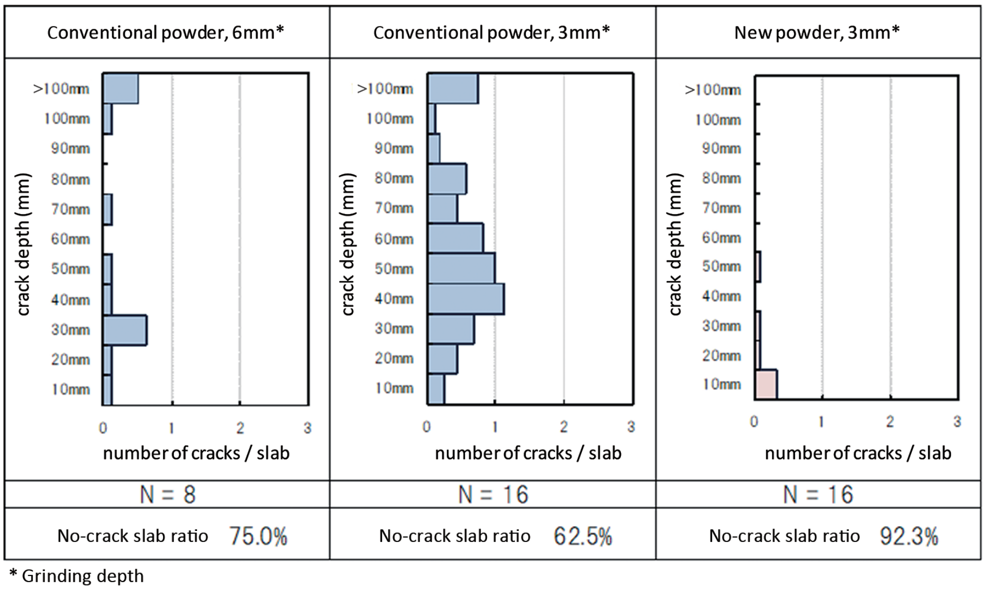

Fig. 13 Number and depth of transverse cracks

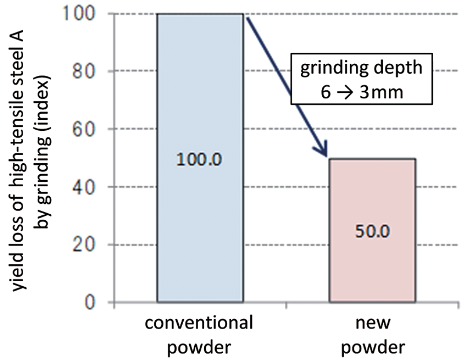

Fig. 14 Improvement of slab yield

in the tundish at the joints has been decreased to half, from 10 to 5 t. In addition, it has been decided that the immersion nozzle is replaced at the timing of the joints between different steel grades, and as a result, the downgrading of steel quality at the joints has been minimized.

6. Summary

Aiming at establishing a more environmentally-friendly process, Nagoya Works has concentrated on the effective and efficient improvement of hot metal pretreatment, secondary refining, and continuous casting to produce high-tensile steel more easily and high-grade steel mass-produced. The improvement of the manufacturing efficiency of eco-products through eco-processes will be developed from this point forward.

References

1) Nagoya Works of Nippon Steel & Sumitomo Metal: Material submitted to 159th Steelmaking Conference of ISIJ. 2018 (for members only)
2) Fukuda, Y. et al.: Shinnittetsu Giho. (394), 91 (2012)
3) Zhang, Y., Fruehan, R.J.: Metall. Mater. Trans. B. 26B, 803 (1995)
4) Eisenhüttenleute, V.D.: Slag Atlas. 2nd Edition. Düsseldorf, Verlag Stahleisen GmbH, 1995, 371p
5) Ogawa, Y., Yano, M., Kitamura, S., Hirata, H.: Tetsu-to-Hagané. 87, 21 (2001)
6) Nagoya Works of Nippon Steel & Sumitomo Metal: Material submitted to 158th Steelmaking Conference of ISIJ. 2018 (for members only)
7) Nagoya Works of Nippon Steel & Sumitomo Metal: Material submitted to 150th Steelmaking Conference of ISIJ. 2014 (for members only)
8) Nagoya Works of Nippon Steel: Material submitted to 145th Steelmaking Conference of ISIJ. 2011 (for members only)
9) Nagoya Works of Nippon Steel & Sumitomo Metal: Material submitted to 149th Steelmaking Conference of ISIJ. 2013 (for members only)
10) Nagoya Works of Nippon Steel & Sumitomo Metal: Material submitted to 157th Steelmaking Conference of ISIJ. 2017 (for members only)
11) Nagoya Works of Nippon Steel & Sumitomo Metal: Material submitted to 155th Steelmaking Conference of ISIJ. 2016 (for members only)
12) Nagoya Works of Nippon Steel & Sumitomo Metal: Material submitted to 152nd Steelmaking Conference of ISIJ. 2015 (for members only)


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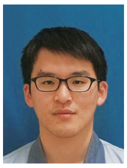
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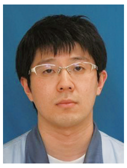
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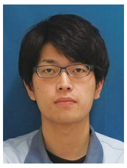
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