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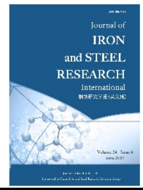

Steel ladle exchange models during steelmaking and continuous casting process

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ABSTRACT

The models and influencing factors of steel ladles exchange during the steelmaking and continuous casting process of H steel plant were investigated. Based on analysis of the operation process and turnover time of steel ladles, relationship models for the turnover number, turnover rate, continuous casting number, number of ladles with additional turnover, and number of ladles without additional turnover were built. The turnover rules of steel ladles for one basic oxygen furnace (BOF) matching one continuous caster (CC) and two BOFs matching two CCs modes were simulated by using a Gantt chart. The models of steel ladle exchange were proposed for casting of a single CC and overlapping casting of two CCs. By analyzing the influencing factors, the following conclusions were drawn. The exchange ladle should not have the task of transporting liquid steel in the CC that stops casting earlier. The end time of the empty ladle in the CC that stops casting earlier should be earlier than the start time of the full ladle in the CC that stops casting later. After evaluating the factors influencing the start casting time, turnover cycle, casting time, continuous casting number, and overlapping time, a prioritization scheme of steel ladle exchange was proposed based on the steel grade. First, the turnover cycle and single heat casting time were determined; based on these, a reasonable ladle turnover number was calculated. Second, the turnover number and continuous casting number were optimized for maximizing the number of ladles without additional turnover. Lastly, to reduce the casting number during the overlapping time to be lower than the turnover number, the overlapping time was shortened.

1. Introduction

A steel ladle is a container used for transporting liquid steel between the basic oxygen furnace (BOF) and the continuous caster (CC) interface[1,2], which is the main tool for controlling the temperature of liquid steel and combining the production process. In general, casting is simultaneously performed by using several CCs. Once a steel ladle completes the assigned transportation task at one CC, it is shifted to other CCs for performing a new transportation task. In other words, steel ladle exchange occurs between CCs. In such a case, the turnover number of steel ladles decreases; moreover, the scheduling difficulty of steel ladles reduces. However, exchange models and influencing factors of steel ladle have not been studied extensively. A previous study on ladle control[3] was performed but focused only on the calculation methods, such as the production calculation method, time calculation method, and turnover period matching method. The existing research is applicable only in an ideal situation involving a single piece of equipment and has several limitations. The turnover rules of a steel ladle were simulated using a Gantt chart[4-6] and a calculation model only considering different overlapping heats was proposed. Besides, a model was previously proposed for calculating the ladle numbers using two and three CCs, which has different overlapping times among casts[7-9]. Moreover, other studies have focused on scheduling management using the matching model[10], numerical modeling[11,12], and queu-

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ing theory[13,14]. The models and factors influencing steel ladle exchange are not adequately discussed.

The operation process and time of steel ladles of H steel plant were analyzed. Relationship models for the turnover number, turnover rate, continuous casting number, number of ladles with additional turnover, and number of ladles without additional turnover were built. The turnover rules of a steel ladle were simulated by using a Gantt chart under the conditions of one CC′s consecutive casts and two CCs′ overlapping casts. Models of steel ladle exchange were built. The factors that influence start casting time, turnover cycle, single heat casting time, continuous casting number, and overlapping time were analyzed. A prioritization scheme of steel ladle exchange was proposed.

2. Analysis of Steel Ladle Operation

H steel plant has two 120 t BOFs, two argon blowing stations (ABSs), one ladle furnace (LF), and two square billet CCs. The CC No. 1 is a bloom caster, and the maximum continuous casting number is 15 heats. The CC No. 2 is a billet caster, and the maximum continuous casting number is 24 heats. Moreover, H steel plant has two online baking positions (ONBP), five offline baking positions (OFBP), one hot repair position (HRP), four cold repair positions (CRP), and two deslagging positions (DP). The operating procedure of a steel ladle is shown in Fig. 1.

Fig. 1 demonstrates that a full steel ladle has two routes of operation: BOF-ABS-CC and BOF-ABS-LF-CC. The product of H steel plant is plain carbon steel, whose production process primarily involves BOF-ABS-CC. An empty steel ladle adopts the DP-HRP-ONBP-BOF process. The durations of the abovementioned operations were measured (Table 1).

Based on the parameters of Table 1, the turnover cycles of steel ladles for CC No. 1 and CC No. 2 were determined to be 147 and 136 min, respectively.

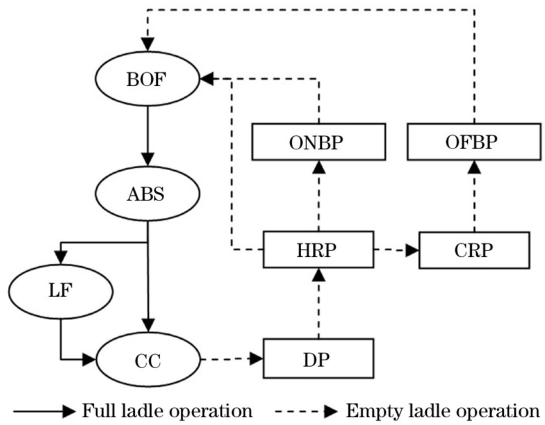

Fig. 1. Operation process of one steel ladle.

Table 1
Operation time of a steel ladle

Time	Time term	Average value/min
Operation time of full ladle	Steel tapping time	4
	Secondary refining time	17
	Transportation time from BOF to CC	21
Single heat casting time	Single heat casting time of CC No. 1	38
	Single heat casting time of CC No. 2	27
Operation time of empty ladle	Deslagging time	5
	Hot repairing time	32
	Transportation time from CC to BOF	30

3. Number Analysis of One Steel Ladle

For a further examination of the models and factors influencing steel ladle exchange, the turnover number of a steel ladle should be confirmed. The relationships between continuous casting number, turnover rate, turnover number, number of ladles with additional turnover, and number of ladles without additional turnover should be controlled first.

(1) Turnover number of steel ladle

There are several established methods for the calculation of turnover number. The turnover number is expressed in Eq. (1)[5,6,9].

$$n_{\mathrm{ladle}}^{\mathrm{CC}}=\left\lceil \frac{T_{\mathrm{cycle}}^{\mathrm{ladle}}}{T_{\mathrm{cast}}^{\mathrm{CC}}} \right\rceil \tag{1}$$

where, $n_{\mathrm{ladle}}^{\mathrm{CC}}$ is the turnover number of steel ladle; $T_{\mathrm{cycle}}^{\mathrm{ladle}}$ is the turnover cycle of steel ladle; $T_{\mathrm{cast}}^{\mathrm{CC}}$ is the casting time of CC′s single heat. The ⌈ ⌉ symbol represents the value rounded up to the nearest integer.

Substituting the parameters shown in Table 1 into Eq. (1), $n_{\mathrm{ladle}}^{\mathrm{CC1}}$ was determined to be 3.87, rounded up to the nearest integer 4. Thus, CC No. 1 requires 4 steel ladles for transporting liquid steel. Meanwhile, $n_{\mathrm{ladle}}^{\mathrm{CC2}}$ was determined to be 5.04; therefore, CC No. 2 requires 6 steel ladles for transporting liquid steel.

(2) Relationship of continuous casting number and number of ladles with additional turnover

In order to finish the task of transporting liquid steel for a single cast, the number of ladles with ad-