NUMERICAL MODELLING OF LIQUID STEEL ALLOYING BY PULSE-STEP METHOD IN SIX STRAND BILLET TUNDISH

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Abstract

The continuous steel casting (CSC) technology has resulted in an increase in steelworks productivity and made it possible to cast billets of a favourable internal structure. Developing and improving the CSC technology for alloy addition feeding to liquid steel for increasing the purity level or correcting of chemical composition grade seems to be quite an interesting approach for advanced steelmaking process. In the tundish, the chemical homogenisation process is controlled by the feed stream and flow control devices. This paper presents the results of investigation describing the process of liquid steel chemical homogenisation in the six strand billets tundish with stopper rod system. The alloy was fed to liquid steel by pulse-step method. Computer simulations of liquid steel flow and alloy addition mixing were performed using the commercial program Ansys-Fluent®. Four tundish variants without and with flow control devices were considered. Additionally computer simulations for four different alloy feeding positions and two type of alloys in the form of nickel and aluminium were performed. Information about the dynamics of steel alloying process was obtained on the basis of fields of liquid steel flow and alloy addition distribution characteristics. For all simulations cases the mixing time was calculated.

Keywords: Continuous casting, tundish, liquid steel, alloying, numerical modelling

1. INTRODUCTION

Continuous casting is a technology commonly used to produce semi-finished products from steel. Smelting and refining processes, characteristic of steel production, relate to the technological stages in which steel subjected to metallurgical treatment occurs in the liquid state. On the other hand, during continuous casting, the state changes from liquid to solid through controlled cooling of steel. Therefore, it is an important technological step shaping the usable properties of the future final product. Liquid steel is delivered to the continuous steel casting (CSC) device station in the ladle from which it is poured into the tundish. Thus, liquid steel is poured into individual moulds through tundish outlets. In industrial practice, 4, 5, 6, 7 or 8-strand CSC machines are used to cast billets, using delta-shaped tundishes [1-5]. In the case of multi-strand tundishes, the main problem is to obtain similar thermal and chemical conditions at individual outlets. Such homogeneity should guarantee obtaining billets of the same properties, being the resultant of the internal structure formed during solidification. Chemical and thermal homogenisation of liquid steel is the effect of the hydrodynamic conditions formed in the tundish by the interaction of the feed stream flowing into the tundish and indirect streams flowing from it into the moulds. The hydrodynamics of steel flow can be influenced by using flow control devices (FCDs) [6-10]. As a result, it improves the mixing conditions of liquid steel or supports refining [11-16]. Commonly used for billets casting six-outlet tundishes most often are fed in the zone between outlets 3 and 4. Therefore, in the tundish without FCDs, the steel flows to these two outlets the fastest, thus for outlets 3 and 4, the time for possible additional metallurgical operations is the shortest. On the other hand, outlets 1 and 6, which are furthest away from the tundish feed zone, are characterized by an extended residence time of liquid steel in the tundish. An additional problem when casting a 6-outlet tundish is to obtain symmetrical hydrodynamic conditions relative to the feed zone. Six-outlet billet tundishes are usually ones with a capacity of up to 30 Mg, therefore, with fairly quick casting they do not have a too long average residence time of liquid steel in the working volume of the tundish. Hence, during casting problems occur with the thermal and chemical homogenisation of liquid steel as well as with clogging of the tundish outlets due to the deposition of non-metallic inclusions (NMI). This paper presents the results of computer simulations regarding the pulse-step method of liquid steel alloying for its chemical correction or NMI modification.

2. TUNDISH DESCRIPTION

The studied object is a delta-shaped tundish with a nominal capacity of 25 Mg. The tundish is equipped with a stopper rod system for regulating the steel inflow to individual moulds. The liquid steel enters the tundish through a ceramic ladle shroud with an internal diameter of 0.08 m. The liquid steel enters the moulds through 6 outlets with an internal diameter of 0.032 m. The level of liquid steel in the tundish is 0.76 m. **Figure 1** presents the liquid steel alloying process initiation sites considered in the research (alloy addition feeding position - AAFP). The alloy addition was introduced into the steel at one (AAFP No. 1 and No. 2) or two (AAFP No. 3 and No. 4) sites simultaneously. Three variants of initiating the alloying process were located in the tundish pouring zone (AAFP No. 1 - No. 3). However, one of the variants assumed feeding of the alloy addition in the area of outlets 2 and 5 (AAFP No. 4). In addition, four variants of the tundish without and with FCDs were researched in the study. The bare tundish (BT) is a variant No. 1. While tundish with subflux turbulence controller (STC) is variant No. 2 (STCT). The STC was described in detail in work [17]. In the third variant regarding the change of the tundish equipment, two low dams with a height of 0.12 located at the outlets were used, the task of which is to protect the stopper rods when the tundish is being poured (LDT). In contrast, in the fourth variant, four high dams were proposed, of which the two extreme ones were additionally equipped with low dams to stimulate liquid steel movement towards outlets No. 1 and No. 6 (HDT). In the fourth variant, the force of the wave entering the tundish during the start of the sequence is strongly limited by a high dam system. The main task of the proposed system of high dams is to increase the potential liquid steel residence time before it reaches the individual outlets.

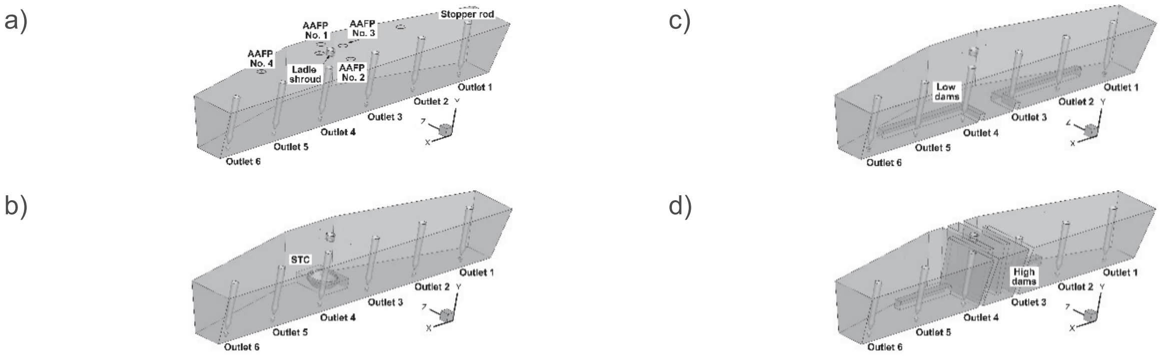

Figure 1 Tundish model: a) bare tundish, b) STC tundish, c) low dam tundish, d) high dams tundish

3. METHODOLOGY

Using the Ansys-Fluent 12.1 computer program numerical simulations were performed for the sequence of casting 0.18 m × 0.145 m billets at a speed of 2.1 m/min. In numerical simulations, the alloy addition in the form of nickel or aluminum was fed to liquid steel by pulse-step method [18]. The purpose of alloying was to adjust the chemical composition of the liquid steel by 0.05 wt%. The liquid steel enters the tundish at the velocity of 1.09 m/s and temperature of 1838 K. Turbulence intensity of liquid steel inflow to tundish was assumed with a turbulence kinetic energy of 0.011881 m^2/s^2 and dissipation rate of 0.032376 m^2/s^3. Properties of liquid steel, nickel and aluminum were presented in the author previous work [19]. Based on the mixing curves, the dimensionless mixing time (DMT) was calculated. The DMT is defined as the time, after which the minimum required liquid steel chemical homogenisation level is maintained, which should amount to at least 95 %. The time interval was expressed by dimensionless time defined by the ratio of the actual time to the average time. The average time for the tundish under examination was 650 seconds. The previous physical and industrials studies have confirmed the usefulness of the numerical model for simulating the macro chemical homogenisation process during steel flow through the tundish [17,20].

4. RESULTS AND DISCUSSIONS

On the basis of computer simulations, the hydrodynamic conditions occurring in the tundish were described. **Figure 2** shows maps of liquid steel flow on a plane located on the axis of the outlets. The liquid steel after entering the tundish is directed along the bottom towards the longitudinal side walls, causing recirculation of the streams in a vertical arrangement. In the outlets zone, liquid steel recirculation zones appear both at the bottom and at its free surface. As they move away from the feed zone and outlet zone, the steel streams circulate horizontally. Using STC in the tundish significantly changes the hydrodynamic conditions in the analysed object. The main stream, after entering the tundish and interacting with the STC, is directed towards the free surface and transverse side walls reaching the zone of outlets 1 and 6. Then the main stream returns to the tundish feeding zone, separating into lateral streams successively feeding successive tundish outlets.

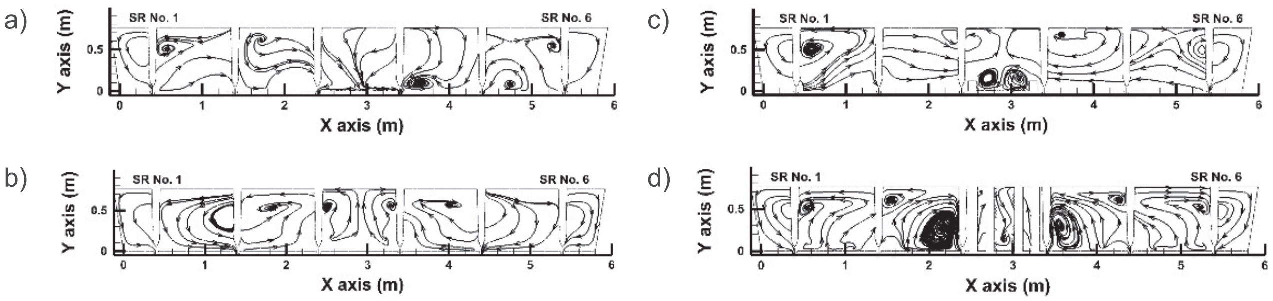

Figure 2 Liquid steel path lines: a) bare tundish, b) STC tundish, c) low dam tundish, d) high dams tundish

A similar hydrodynamic system with streams flowing into the feeding zone occurs in a tundish with low dams. However, in the zone of stopper rods 2-5, the steel movement has an ascending or horizontal character with respect to the bottom of the tundish. In the tundish with low dams outside the stopper rod zone, additional areas of liquid steel circulation are created. In addition, back streams flowing into the feed zone stimulate the flow of the main stream towards the free surface. However, the use of high dams in the tundish causes the creation of two liquid steel circulation areas in close proximity to stopper rods 3 and 4. The liquid steel movement in the zone of stopper rods 2-5 is definitely ascending. On the other hand, outside the stopper rod zone, after leaving the feed zone and dam system, the steel flows into the individual outlets from the free surface. All the proposed variants of the tundish equipment definitely affected the hydrodynamic system, significantly modifying it especially in the regions of liquid steel alloying process initiation. Numerical simulations concerning chemical homogenisation were carried out for all the considered variants of the tundish equipment and the initiation sites of alloy addition feeding, both Ni and Al. **Figure 3** shows the curves of mixing the alloy addition with the liquid steel. **Figure 3a** shows the curves for a tundish without FCD and AAFP No. 1. In the analysed variant, the Ni concentration level of 0.05 wt% was not reached because some of the curves after stabilization of the liquid steel addition mixing process is located below or above the 95 % chemical homogenisation zone. It can also be seen that there is quite a significant difference in the value of the initial peak, which definitely confirms the asymmetric distribution of the addition in the initial phase of alloying. The chemical homogenisation process is definitely influenced by the choice of the alloying process initiation site. As can be seen in **Figure 3b**, with the same tundish equipment appropriate selection of the initiation site will result in obtaining the required level of chemical homogenisation in a very short time of mixing.

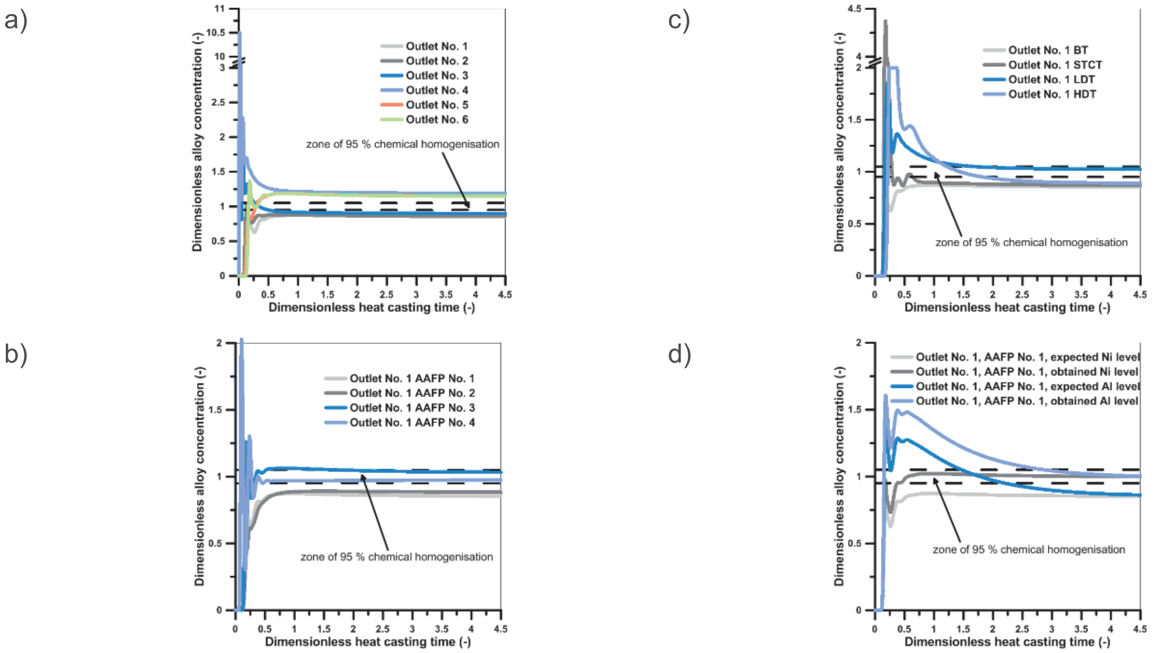

Figure 3 Mixing curves: a) bare tundish, AAFP No. 1 and Ni, b) bare tundish and Ni, c) all tundish variants and Ni, d) influence of concentration reference point

The chemical homogenisation process is also significantly influenced by the tundish equipment, which, by affecting the flow of liquid steel, may make it impossible to attain the assumed level of chemical correction of the cast steel grade (**Figure 3c**). In order to assess the suitability of the proposed method of feeding the alloy additive to liquid steel as part of the research, mixing curves were generated not only in relation to the expected Ni or Al concentration, but also for the concentration actually obtained at the end of heat casting. The analysis showed that it is possible to obtain a constant level of the applied alloy addition, however, the reference level is crucial because in the case of an even distribution of the addition in the liquid steel volume in relation to the feed zone, the expected level of its concentration at the outlets is impossible (**Figure 3d**). Nonetheless, the actual concentration level of the alloy addition can be far from satisfactory for the solidification quality in the continuous casting mould. **Figures 4a** and **4b** show the mixing times for the required and actually obtained concentration level of alloy addition. The expected level of chemical composition correction for both Ni and Al was obtained only by the AAFP No. 3 and in the case of the tundish without FCD and with low dams. The resulting mixing times for a tundish without FCD and individual outlets are comparable (**Figure 4a**). Nevertheless, while low dams shortened the mixing time, asymmetry in chemical homogenisation was particularly noticeable in the case of outlet No. 6. However, the dissolution process of the addition with a much lower density than liquid steel is much slower. For a more advantageous variant of alloying process initiation, mixing time analysis was also carried out for all the considered variants of tundish equipment, but in relation to the actually obtained concentration of alloy addition (**Figure 4b**). With the exception of the tundish with high dams, mixing times below 0.75 DMT were obtained with a satisfactory level of mixing time asymmetry for individual outlets. The presented mixing times in relation to the actually obtained Ni concentration levels at individual outlets can be considered as useful from the technological point of view if the level of deviation of the obtained correction in relation to the expected level is analysed. The smallest deviations were obtained for alloying process initiation variant No. 3 in the tundish without FCD, where the deviations did not exceed 0.002 %, which resulted in obtaining the expected level of correction of the chemical composition of the cast steel grade at individual outlets (**Figure 4c**). In most cases, however, these deviations were significant and in extreme cases the level of Ni concentration was 100 % higher than expected (**Figure 4d**). The deviations related to aluminum were similar to those presented for Ni and did not differ by ±0.0005 %.

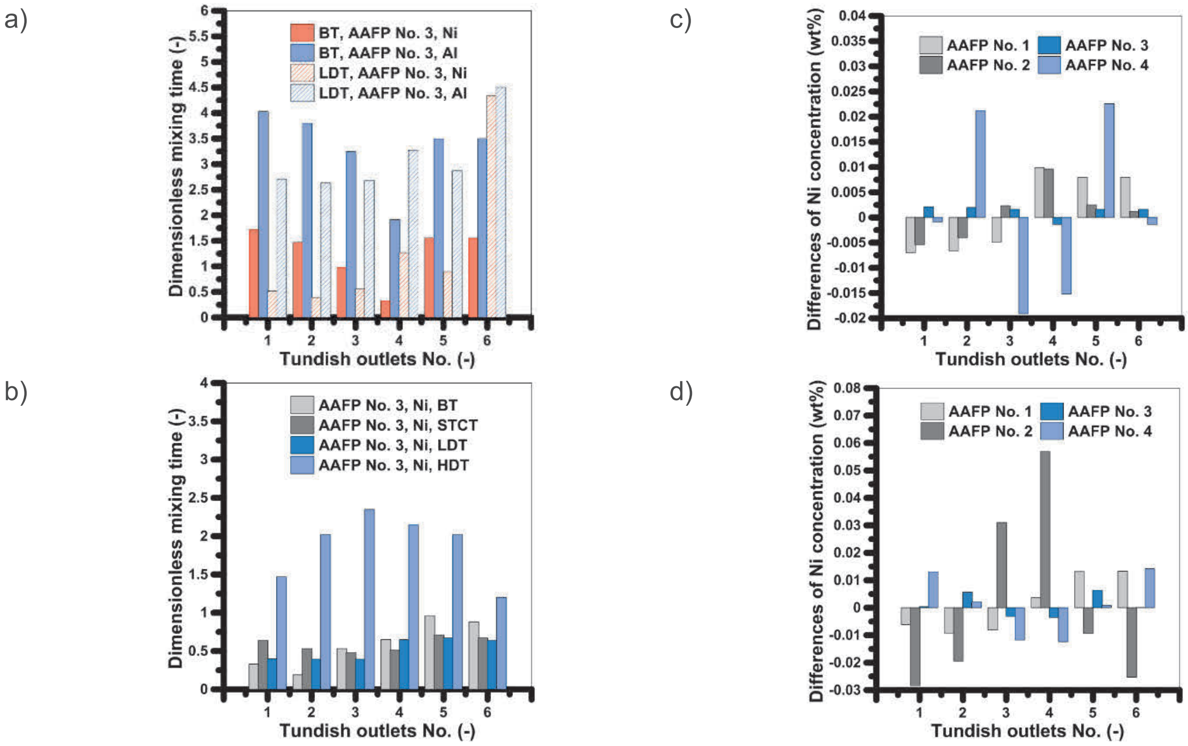

Figure 4 Mixing time (MT) and Ni concentration differences (NCD): a) MT for expected alloy concentration, b) MT for obtained alloy concentration, c) NCD for BT, d) NCD for STCT

5. CONCLUSION

Based on the computer simulations carried out, it has been found that:

- In the considered tundish, initiation of the steel alloying process only at one site, despite a location symmetrical relative to the outlets, leads to significant asymmetry in the chemical homogenisation recorded at the individual tundish outlets.
- Initiation of the alloying process outside the tundish feeding zone did not allow the required level of chemical homogenisation to be obtained at individual outlets.
- The most effective solution enabling the assumed level of alloy addition in liquid steel to be obtained with a similar mixing time was initiation of the alloy addition simultaneously at two sites in the pouring zone of a tundish not equipped with FCD.
- The use of low dams shortened the mixing time of the alloy addition both for Ni and Al, however, an unfavorable phenomenon of chemical homogenisation asymmetry with respect to the feeding zone appeared.
- The proposed pulse-step method ensures obtaining a constant level of alloy addition at individual outlets in times below 0.5 DMT and 2.5 DMT for Ni and Al, respectively. Nonetheless, the hydrodynamic structure occurring in the analysed object makes it difficult to achieve the assumed concentration level of the additive, leading to a discrepancy between the assumed and achieved Ni and Al concentrations in the liquid steel entering the moulds.

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