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Simulation of solidification microstructure in twin-roll casting strip

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ABSTRACT

The twin-roll strip casting is regarded as the most prospective technology of near-net-shape casting. The control of the grain structure is of primary importance in twin-roll strip casting because the solidification microstructure has great influence on the quality and mechanical properties of strips. In this paper, a three-dimensional cellular automation (CA) finite-element (FE) model within CALCSOFT3D package is used to simulate the microstructure of steel strip twin-roll casting. The Gaussian distribution of nucleation sites is adopted both at the mold surface and in the melt. The KGT model is used to describe the growth kinetics of dendrite tip. Then the influence of the casting conditions such as pouring temperature and heat transfer coefficient between the rolls and the solidified strip on the strip solidification microstructure is detailed investigated. The predictions show that the temperature profile and solidification microstructure are most sensitive to the pouring temperature. And with the increase of the pouring temperature, grain density obviously increases. However, the influence of three bottom cooling conditions on microstructure formation has little difference in this study.

1. Introduction

The strip casting process has been researched and developed over the years. Among the various strip casting processes applied to steelmaking, the twin-roll strip casting is regarded as the most prospective technology of near-net-shape casting. Twin-roll strip casting may save energy and manufacturing cost by eliminating some of the intermediate stages [1–4]. Furthermore, it can produce better properties due to high cooling rate.

The control of the grain structure is of primary importance in twin-roll strip casting because the solidification microstructure has great influence on the quality and mechanical properties of strips. The microstructures of strip steel depend on the casting process parameters, and microstructure has a great impact on its properties [4]. Therefore, to find out the disciplines of microstructure formation in roll casting is an economical and feasible way to optimize the parameters of casting process and to get high quality strip by the calculation and prediction of casting process.

In the last decade, many kinds of methods about solidification structure simulation [5–13] have been presented, which can be summed up in three main categories: deterministic simulation, stochastic simulation and phase-field simulation. The cellular automation (called CA) method belongs to stochastic simulation. CA methods have been developed for the prediction of dendrite grain structures formed in solidification processes [10–16]. Based on physical mechanism of the process of nucleation and kinetics of grain growth, the size and distribution of grain can be got, and the formation of columnar grains and the conversion from columnar grains to equiaxed grains can also be described by CA. Gandin et al. [13] combined a three-dimensional (3-D) CA algorithm with finite-element (FE) heat flow calculation for applying their model to non-uniform temperature situations and have obtained some reasonable results. Liu et al. [14,15] has coupled the heat transfer and CA procedure to predict the solidification structure of aluminum twin-roll casting and analyzed the effects of casting speeds.

In this study, a 3-D cellular automation (CA) finite-element (FE) model with CALCOSOFT3D package was performed to simulate the solidification structure of twin-roll casting strip. Then the influence of the casting conditions especially such as heat transfer coefficient and superheat on the strip solidification microstructure was detailed investigated. And according to the simulation results, some suggestions were given to improve the strip quality.

2. Mathematical model

2.1. Physical model description

In a twin-roll strip casting process, the molten steel is supplied through a delivery system into the special mold formed by the two-counter rotating water-cooled rolls and two side dams. The molten steel is solidified in an extremely short time and exits out from the rolls in the form of strip. Fig. 1 shows the process of pour-

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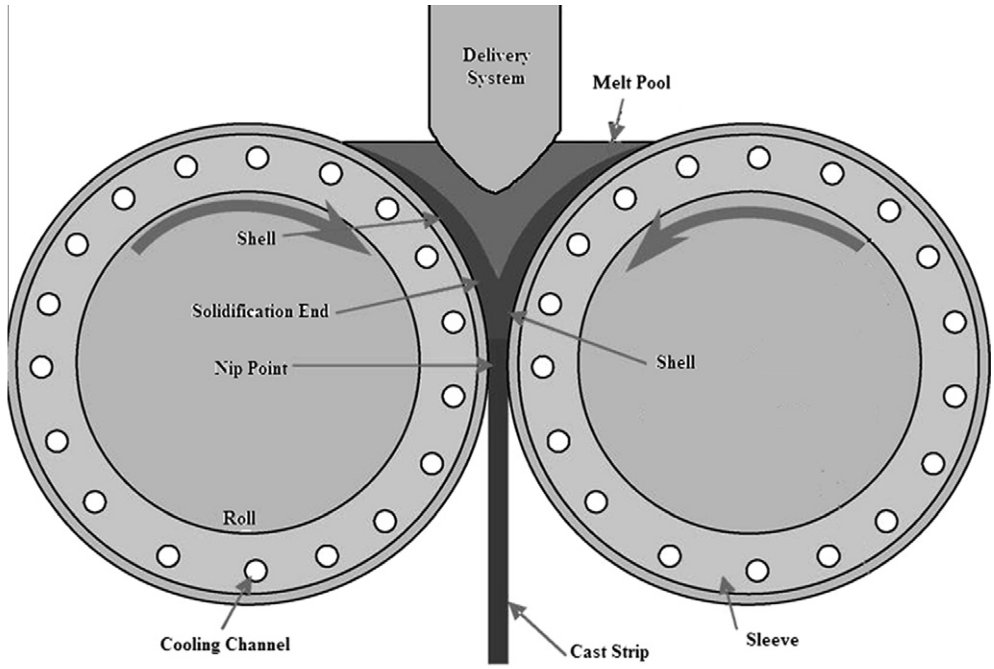

Fig. 1. Schematic representation of the twin-roll strip casting process.

ing molten steel in between the two rotating rolls and then the solidified shells are rolled near the roll nip after being solidified onto them.

Fig. 2 presents the solidification process of twin-roll casting strip. To reduce the calculation time, the computing region of solidification process should be simplified as a micro-unit (cube), which size is 0.5 mm × 0.5 mm × 1 mm. The strip solidification process is studied using CAFÉ model in this cube of a twin-roll strip casting. The cooling conditions of the process could be described as follows: a cooled chill is put under the bottom of the cube, so some interfacial heat coefficients were deduced to describe the heat transfer between the steel and water-cooled rolls. An imposed temperature is assumed for the top of the cube. The symmetric boundary condition is considered at both sides of the cube. The thermal properties and nucleation parameters of the steel strip are respectively shown in Tables 1 and 2.

Table 1
Thermal properties for Fe–C alloy strip [16].

Property	Value
Density	7300 kg/m^3
Thermal conductivity	50.66 W/m °C
Specific heat	569.43 J/kg °C
Solidus temperature	1500 °C
Liquidus temperature	1538 °C
Latent heat	272 kJ/kg

During the computing, larger mesh is used to simulate the temperature field, and the cell meshes with smaller size are used for simulation of micro nucleation and growth, then the micro cell temperature can be got by interpolation of macro-cell temperature in space and time. The size of macro-cell is 0.5 mm × 0.5 mm × 1 mm, which is further divided into 100 × 100 micro cells.

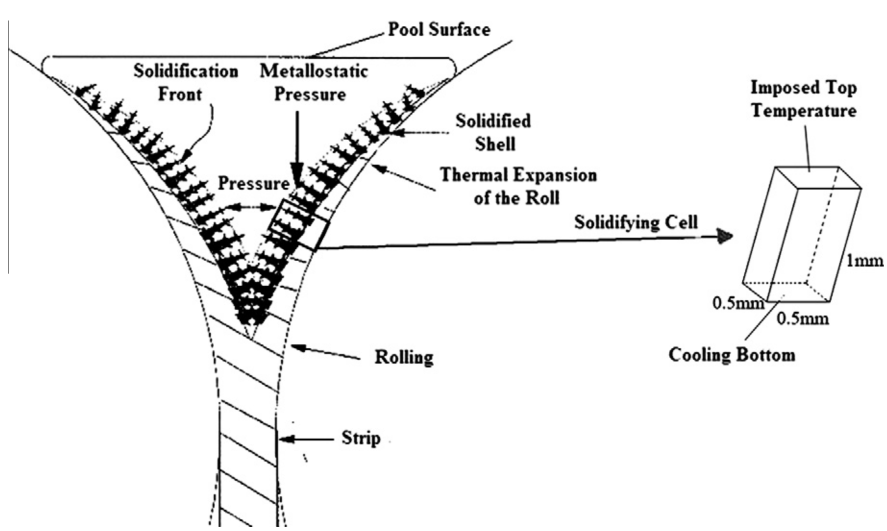

Fig. 2. Schematic of solidification process of strip.