An Improved Double Hot Thermocouple Technique for Mold Slag Investigation

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INTRODUCTION

In the continuous casting process, mold powder is added to the top of the liquid steel pool. In contact with the steel, a liquid slag is formed and infiltrates the gap between the strand and the mold, where a liquid slag film close to the strand, a glassy layer in contact to the mold and in between a crystalline layer is formed. The structure and thickness of these layers considerably influence the horizontal heat transfer from the strand to the copper mold. Therefore, the Double Hot Thermocouple Technique (DHTT) has already been implemented to in-situ investigate the crystallization behavior of mold slags under near service conditions. The main parts of this equipment are the experimental unit, the hot thermocouple drivers and a video capture system. During the experiment, a slag is stretched between two platinum wires of different temperatures to simulate the temperature gradient of the process [1, 2]. The platinum wires are located within the experimental unit, which may also act as a vacuum chamber [3, 4]. Some devices also contain a supplemental heater close to the platinum heating wires to reduce heat loss from the sample surface (Figure 1a). The heating wires are made from a type-B thermocouple welded without a beat. The electrical supply is realized via the hot thermocouple drivers enabling sample heating and temperature measurement simultaneously. This is achieved via a silicon-controller rectifying the electric current into two half-wave: one for the heating cycle and to reduce sample noise only 1/3 of the following for temperature measurement. Some devices additionally have an air-cooling component to increase the cooling velocity of the sample for isothermal experiments (see below) [4, 5].

Three different procedures are used to investigate the crystallization behavior of mold slags with the DHTT [6]. In all cases, the sample is liquefied between the platinum wires until a homogeneous slag is formed. For isothermal experiments, it is then quenched to a selected temperature in order to investigate the crystallization behavior. Therefore, the images of the slag in dependence on the experimental time are evaluated. Subsequently, time-temperature-transformation (TTT) diagrams for selected crystalline fractions are created. In the case of continuous cooling experiments, the sample is cooled with defined cooling rates. With this procedure, continuous-cooling-temperature (CCT) diagrams showing start and end of crystallization are realized. For continuous cooling experiments with different thermal gradients, one of the heating wires is cooled with selected cooling rates from the maximum temperature (e.g. 1500°C), whereas the other remains fixed after quenching to a defined temperature. Different morphologies of the crystals formed enable partitioning of the solidified slag film into areas.

A large number of experiments have already been carried out to investigate both the melting [6-9] and crystallization behavior [6, 7, 9-14], as well as the crystallization in dependence on the temperature gradient within a slag film [3, 15, 16]. Furthermore, the DHTT was used to observe the effect of water vapor on crystallization [14, 17], to measure the heat transfer...