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OPTIMISATION OF REFRACTORY COMPONENTS OF SLIDING GATE MECHANISM FOR CONTINUOUS CASTING

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ABSTRACT

New design techniques have been developed to optimize refractory components of sliding gate mechanism for continuous casting of steel. The overall objective is to increase CC productivity as well as steel quality by using optimized refractory from ladle to tundish. These techniques allow the prediction of steel and refractory chemical interactions and, thus, steel chemistry evolution as well as build up and corrosion occurrence. The recent developments resulted in optimized refractories for sliding gate plates that meet the various continuous casting conditions. Furthermore, fracture mechanical measurements were established as a useful tool in the selection and development of slide gate refractories. The mechanical FEA evaluations take into account specific mechanical behavior of refractory components as well as high temperature evolution of their properties.

KEYWORDS: continuous casting, refractory interactions, plate refractory properties, corrosion, thermal shock resistance

1. Introduction

The development of the continuous casting process resulted in a longer residence time of the molten steel in the steel casting ladle. The ladle stopper could no longer survive in this severe environment; an alternative device had to be implemented.

The ladle sliding gate resolved this problem and allowed longer and more sophisticate ladle secondary metallurgy to be utilized, resulting in better steel quality.

The refractory plates were exchanged after one heat in a similar manner as with stoppers, people quickly realized the potential to achieve multiple heats and to improve the reliability and workability of the systems.

The initial sliding gates were labour intensive and required a lot of care because the refractory plates were assembled with mortar into the mechanism attached to the ladle bottom. Precise torque wrench adjustment of the locking and pressure nut was essential. These rigid systems provided poor thermal expansion compensation.

The refractory materials available were not capable of resisting to the combined effects of high temperature, thermal shock, mechanical stress and corrosion.

Some system suppliers resolved the problems by designing exchangeable cassettes assembled with the refractory components in a separate workshop. Others preferred to manufacture ready-to-use canned refractories installed in “door type” mechanisms at the ladle preparation area.

Although the linear sliding gates with hydraulic actuator became the most popular, some rotary gates with electric drive showed particular merits.

Different kinds of refractory materials were progressively developed to obtain better technical and economical performances and also to improve workers’ health environment.

The traditional approach of refractory component development based on empirical evaluation is now showing clear limitations in most demanding fields like steel continuous casting. To improve the performances of steel flow control there were developed new approaches in order to better understand the high temperature behavior of refractory components. One of the main objectives was to precisely evaluate steel refractory interaction to determine corrosion mechanisms. This has been achieved by coupling specific experimentation and thermodynamic evaluation. A second objective has been to determine high temperature mechanical behavior of refractory components, which are composite products. The implementation of specific properties allows improved design of components and evaluation of material characteristic influences [1].

Finally the development of dedicated fluido-dynamic codes allows the prediction of physical and chemical phenomena occurring during steel continuous casting [2].

2. Steel inclusions and refractory interface

Using thermodynamic modeling, steel inclusion volume and type are calculated based on the total steel composition as shown on the right side of Figure 1. The newly formed oxides at the interface from steel dissolved components (like Al, Mn, Si, Ti) is determined by SEM/EDS observation [3].

The example below corresponds to a Si-killed structural steel with a total amount of 27 ppm of liquid calcium-aluminum silicate inclusions at tundish temperature (1520 °C).

New oxide precipitation at the interface is depending on steel composition and new species coming from the refractory. The new interface formed is reducing the reaction rate mentioned above. A glassy interface will progressively stop the gas transfer to the steel and thus halt the carbon dissolution.

2.1 Corrosion and build up mechanism

A new local equilibrium is subsequently established between new precipitates and existing inclusions in the steel flow [4]. Depending on refractory reactivity and inclusion modification at the interface, one can establish the stability of the steel refractory interface based on the following principles:

2.1.1 Corrosion

When the newly established local equilibrium at the refractory interface is leading to an increased liquid phase, compared to the initial content in steel oxide inclusions, the refractory interface is eroding.

Considering the inclusions in the silicon-killed steel of the previous example, if they come into contact with an alumina-based refractory, those inclusions will dissolve the refractory generating more liquid than the initial inclusion volume.

As can be seen in the model result below, the initial 27 ppm of inclusions only become saturated in alumina and the erosion stops after dissolving 30 g of refractory. In other words, the casting of 1000 T of steel like in the example from Figure 2, has an erosion potential of 30 kg of Alumina, which is in the range of the total amount of flow control refractory in a slab caster.

In Figure 2 at left is the inclusion evolution path from its original composition until the alumina saturation that is detailed semi-quantitatively and qualitatively at the right. The 27 ppm of inclusion in the steel of the example will not attack uniformly the whole refractory. The erosion will be concentrated on the flow regulation control point.

2.1.2 Build up mechanism

When the solid content of the interface is increasing compared to the solid fraction of steel inclusions, an agglomeration or build-up situation occurs at the refractory interface [5, 6]. An example of observed alumina build is shown in Figure 3.

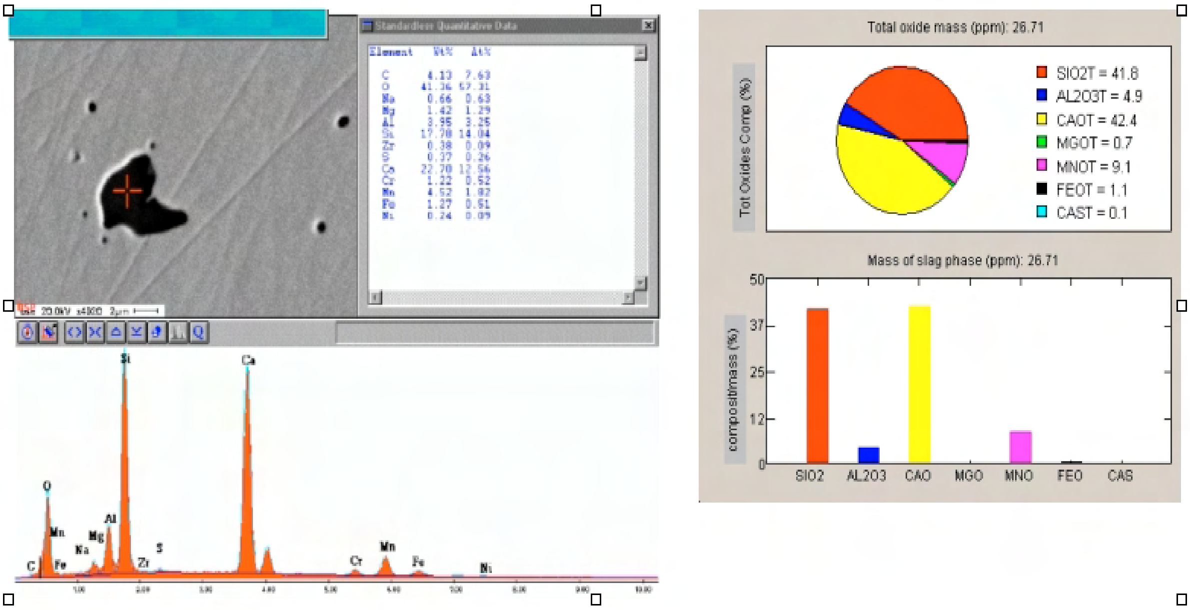

***Fig. 1.** Steel inclusion determination*

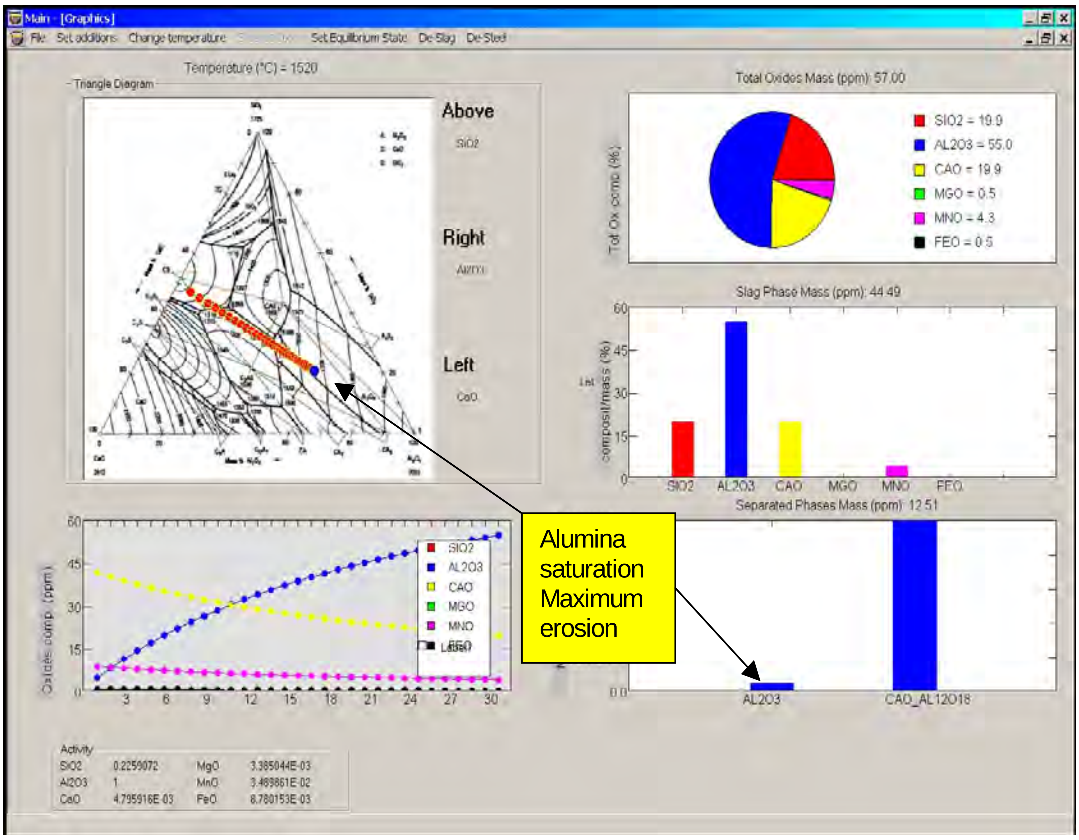

Fig. 2. *Computer modeling of Alumina dissolution in the inclusions.*

The consequences of corrosion and build-up are, for both, a reduction of casting time [7]. So the optimization of the refractory is to obtain a stable interface for a given steel quality.

The thermochemical models developed to simulate refractory interactions and the evaluation of inclusion status depending on steel quality allow a rational refractory choice.

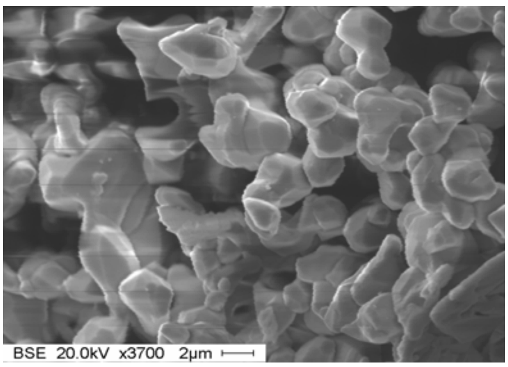

Fig. 3. *Alumina inclusions agglomerated inside a continuous casting alumina/graphite nozzle.*

3. Refractory Properties and Selection

The refractory parts of a slide gate system include the well block, the upper nozzle, the fixed and slider plate, and the lower nozzle. All these parts are subjected to specific in service stresses and must be carefully designed and developed from the specific refractory grades. Typically, the service life of the refractory components is determined by the slide gate plates. These become worn by a combination of affects, including corrosive attack and infiltration by the steel melt, thermal cycling due to multiple rounds of heating up and cooling down, oxidation by oxygen from the air, and abrasion and mechanical stress due to plate movement and clamping of the system [8].

Depending on the casting conditions and the steel grades produced at a specific steel plant, one of the aforementioned wear mechanisms predominates and limits the refractories' service life. Furthermore, the type and size of the slide gate system primarily dictate the type and grade of plate refractory selected.

When examining the plate refractory properties there is a number of major factors to consider. Clearly, the chemical composition is very important. For example, magnesia material is far more corrosion resistant than all other refractories but has limiting mechanical properties, including high thermal expansion and low grain hardness. There is a clear and well established correlation between high density (low porosity) and high mechanical strength and abrasion resistance [9]. The typical methods to measure these properties are the modulus of rupture (MOR) and abrasion resistance by sandblasting.

These particular properties are very high in both fired and carbon-bonded alumina grades. Thermal shock resistance is difficult to measure for carbon-containing material; therefore, the modulus of elasticity and the MOR are used as criteria for selection. All these techniques are used in slide gate development; however, they are not always sufficient to select the optimum material, particularly in relation to the fracture behavior. Therefore, fracture mechanical methods have been adapted and applied to slide plate material characterization.

4. Fracture Mechanics – a tool for refractory development

Currently, there are two principal test types to analyze fracture mechanics: (1) - determination of the minimum shock to initiate cracking, and (2) - determination of the amount of damage sustained by a fixed shock, or series of shocks [10]. The following parameters have been proposed to predict the results of such tests: a thermal-stress-resistance parameter and a thermal-shock-damage-resistance parameter [11]. The latter, which relates to minimizing the extent of the crack propagation, is considered to be more significant for coarse ceramic slide gate refractories. This relates to the fact that a coarse ceramic structure always contains numerous flaws and that in slide gates cracking due to thermal stress caused by rapid heating by molten steel is unavoidable because of the temperature difference between the casting start-up at 100-200 °C and the flowing molten steel at 1500-1600 °C. The magnitude and nature of the thermal stresses are strongly dependent on various parameters, including the plate shape, the plate fixation method, and possible steel banding. However, the resulting in service crack patterns and crack opening has to be controlled by the refractories' properties [12, 13].

Until recently, the modulus of elasticity and MOR has been employed to estimate the thermal shock resistance of these materials prior to practical tests. However, these relate to crack initiation rather than propagation and do not encompass important factors including thermal expansion.

To estimate thermal shock resistance various thermal stress resistance parameters have been developed. For example, the R_{st} value, which is proportional to the minimum temperature difference required to initiate the propagation of large cracks under thermal shock conditions, is calculated using the following formula:

$$R_{st} = \left(\frac{G_f}{E \cdot \alpha^2} \right)^{\frac{1}{2}} \qquad (1)$$

Where R_{st} is the thermal stress resistance parameter (K.m$^{1/2}$), G_f is the work of fracture (J/m^2), E is the elastic modulus (GPa), and α is the thermal expansion coefficient (1/K).

The calculation of R_{st} and other parameters related to crack propagation requires G_f to be determined for the approximate in service temperature in the bore vicinity during casting.

One method to determine G_f in coarse-grained materials is based on a wedge splitting test that enables stable crack propagation in sufficiently large specimens [14]. The principle of the wedge splitting test is illustrated in Figure 4.

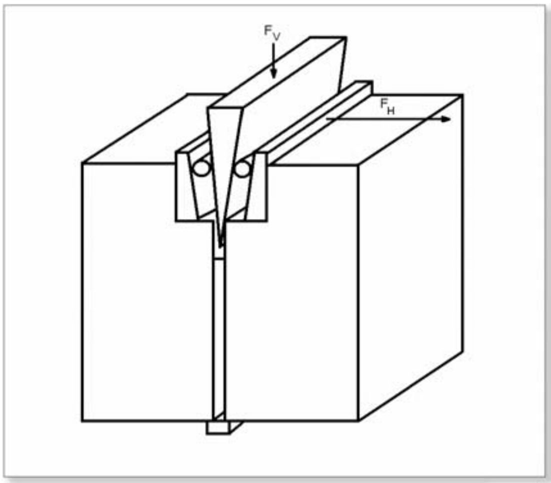

Fig. 4. *The principle of the wedge splitting test. The arrows indicate the vertical force (FV) and horizontal force (FH)*

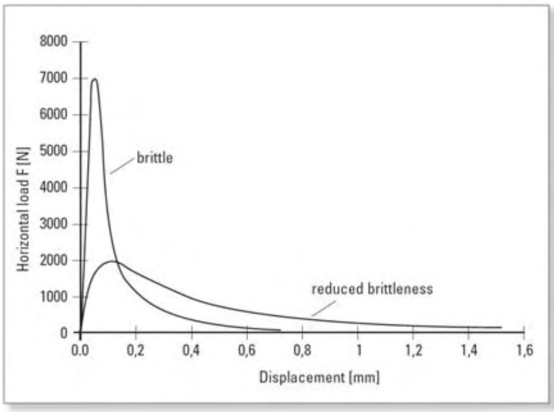

Fig. 5. *Typical load versus displacement graph*

A loading device composed of the wedge, two rolls, and two load transferring pieces is positioned in a specimen groove. Furthermore, the specimen has a starter notch and two side notches. The load of the testing machine is applied vertically to the wedge and both the load and displacement are recorded. A typical load versus displacement graph is depicted in Figure 5. The work of fracture corresponds to the area under the curve. This method has been extensively employed at both room temperature, and at elevated temperatures in an oxidizing atmosphere for refractories with ceramic bonding.

5. Conclusion

Increasing demands for steel quality and continuous casting productivity require new approaches in terms of refractory component development. Advanced refractory design is achieved by coupling dedicated thermochemical and thermomechanical models. When appropriate material behavior at operating temperatures is experimentally demonstrated and validated, model results provide innovative solutions for refractory component optimization. These new approaches, combined with empirical field experience, are necessary to improve current and future steel continuous casting process. In this paper the properties and underlying design principles of the newly developed slide gate generation have been described. Currently, the in service results from the steel plants indicate a significant increase in performance compared to conventional slide gates. Furthermore, the introduction of an adapted wedge splitting test has resulted in a fracture mechanical method for effective slide gate plate refractory selection. The superior in service performance of slide gates can only be achieved by the concurrent development and design of both the slide gate system mechanisms and the appropriate refractories.

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