

# Advanced design of refractory components for continuous casting

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*New design techniques have been developed to optimize continuous casting refractory components. The overall objective is to increase CC productivity as well as steel quality by using optimized refractory from tundish to mold. Those techniques allow to predict steel and refractory chemical interaction and, by thus, steel chemistry evolution as well as build up and corrosion occurrence.*

*Specific fluido-dynamic models have also been developed to better take into account physical parameters at refractory interface and to optimize steel flow control. The CFD model can be coupled with refractory chemical interaction to simulate steel chemical evolution.*

*These two different approaches result in shape and material modifications. They are completed by dedicated thermal stress analysis in order to improve thermal shock resistance. Those mechanical FEA evaluations are taking into account specific mechanical behavior of refractory components as well as high temperature evolution of their properties.*

Parole chiave: acciaio, refrattari, colata continua

## INTRODUCTION

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, Vesuvius has developed with partners, new approaches in order to better understand high temperature behavior of refractory components.

One of the main objective was to precisely evaluate steel refractory interaction to determine corrosion mechanisms. This has been achieved by coupling specific experimentation and thermo-dynamical evaluation.

A second objective has been to determine high temperature mechanical behavior of refractory component which are multiphase composite products. The implementation of those specific properties in FEA codes allows improved design of components and evaluation of material characteristics influence.

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

## CHEMICAL BEHAVIOR REFRATORY COMPONENT DURING STEEL CASTING

The classical experimental evaluation of steel corrosion is not enough to determine refractory component. Standard experimentation are conducted with limited amount of steel, while in reality steel is continuously renewed at refractory interface.

The second limitation faced today is that refractory interface is, in reality, controlled by variables like steel dissolved elements and steel inclusions. For instance, the volume of inclusion during continuous casting is comparable to the volume of refractory components used so they have a strong influence on steel refractory reactivity.

So the only possible approach to corrosion is to determine experimentally mass transfer from refractory to steel and to extrapolate to continuous casting conditions.

### Steel and refractory interaction model

To precise the nature of chemical reactions, specific experiments have been conducted:

For the first type of experiment, pure iron is melted in an induction furnace with tailored alloys addition. A rotating refractory sample is place in the melt and steel chemical composition change are determine by steel sampling during the experiment.

A second set of experiment consist to degassing evaluation on refractory samples using a mass spectrometer at increasing temperature.

For the different type of refractory composition used in steel casting the following major reaction have been determined and quantified:

- Carbon dissolution  $C \rightarrow C$
- Silica reduction  $SiO_2 + C \rightarrow SiO(g) + CO(g)$
- Magnesia reduction  $MgO + C \rightarrow Mg(g) + CO(g)$
- Zirconia reduction  $ZrO_2 + 3C \rightarrow ZrC + 2 CO(g)$
- Oxides dissolution  $MxOy \rightarrow xM + yO$

The different reaction kinetics have been determined depending and steel grade, refractory composition and microstructure and physical parameters at refractory interface (pressure, temperature).

The results is a mathematical program which calculate the flow rate of species passing from the refractory interface to the steel.

### Steel inclusions and refractory interface

Using commercially available thermodynamical software, steel inclusion volume and type are determined based on total steel composition.

Secondly, the new formed of oxides at the interface from steel dissolved components (Al, Mn, Si, Ti) is determine by SEM EDAX observation.

New oxides 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 men-

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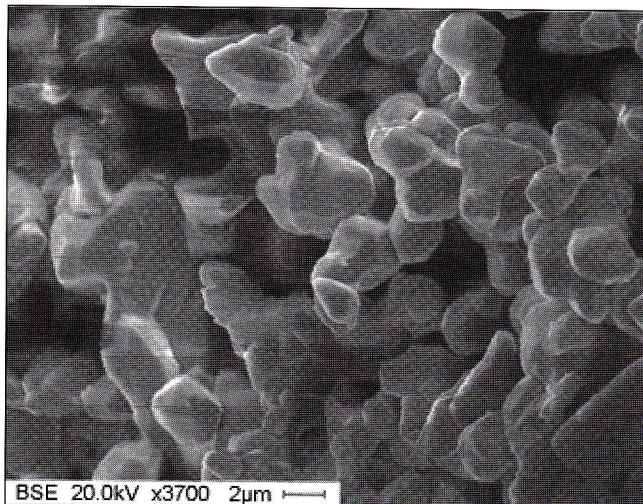


Fig. 1 - Alumina inclusione agglomeratarion inside a continuous alumina graphite nozzle.

Fig. 1 - Deposito di Allumina in uno scaricatore paniera.

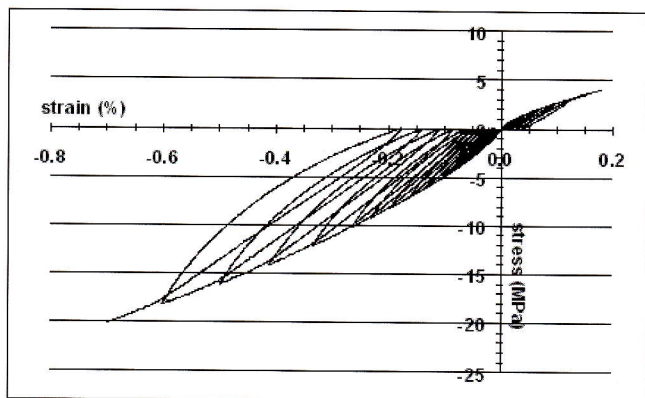


Fig. 2 - Stress behavior of alumina graphite in tension and compression.

Fig. 2 - Andamento degli sforzi di tensione e compressione per una miscela a base di Allumina-Grafite.

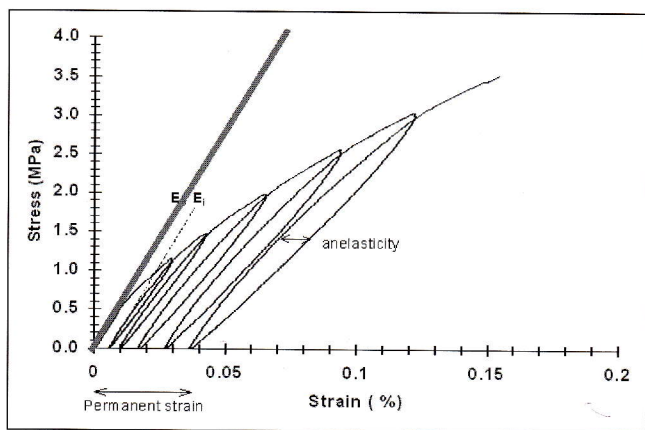


Fig. 3 - Tension behavior of alumina graphite.

Fig. 3 - Comportamento in tensione di una miscela a base di Allumina-grafite

tioned above. A glassy interface will progressively stop gas transfer to steel and carbon dissolution.

**Corrosion and build up mechanism**

A new local equilibrium is then established between new precipitates and already existing inclusions in the steel flow. Depending on refractory reactivity and inclusions modification at interface, one can establish the stability of the steel

refractory interface based on the simple following principle:

- When the new local equilibrium at refractory interface is leading to increased liquid phase compared to the initial content in steel oxides inclusions, the refractory interface is eroding .
- When the solid content of the interface is increasing compared to the solid fraction is steel inclusions, an agglomeration, build up situation at the refractory interface. An example of observed alumina build is shown at figure 1.

The consequences of corrosion and build are, for both, a reduction of casting time. So the optimization of the refractory consists to obtain a stable interface for a given steel quality. The thermo-chemical models developed to simulate refractory interaction and the evaluation of inclusions status depending on steel quality allow a rational refractory choice.

**MECHANICAL BEHAVIOR OF STEEL CASTING REFRACTORY COMPONENTS**

The mechanical behavior of refractory component is by far more complex than generally admitted. This is mainly caused by the multiphasic nature of the component and the large temperature range in use.

Refractory material behave like composite structure with specific feature coming from the phase transformation occurring at high temperatures.

The standard mechanical evaluation like 3 point bending or sonic measurement of elasticity induce important approximation in thermal shock evaluation. The consequence is also non-appropriate choices for product design.

**Example of mechanical properties**

Cold mechanical properties of standard alumina graphite composite has been evaluated in tension and compression mode.

The results presented in figure 2 and detailed in figure 3, are typical for graphite containing material used in continuous casting.

The important difference between tension and compression are classical for ceramic but the relative important plasticity observed is characteristic of biphasic composite.

One major consequence is that strength determined by 3 point bending strength is over estimated when compared to tension strength which is the main failure mode.

The sonic determination of elasticity is only valid for limited strain while the real pseudo elasticity is much lower. This leads to overestimated stress level caused by thermal gradient. Finally the permanent strain occurring during thermal loading needs to be taken into account for thermal cycling.

**Thermo-mechanical stress models**

Standard Finite Element Analysis (FEA) codes don't take into account specific refractory properties. In order to overcome this problem Vesuvius is developing dedicated FEA tools which takes into account refractory material specificity.

The commercially available basic code (Abaqus) is implemented with subroutines which, incrementally, give a more precise model of refractory thermal loading.

Those subroutine take in account phenomena as anelasticity, creep deformation or phase change.

Model results are compared with sensitivity analysis and validation experimentation in order to ensure results validity.

**Material and design development**

The thermal cycling of continuous casting refractory generates very different stress level during operating time. The different stress evolution between transient heating and stationary working condition needs to be carefully analyzed

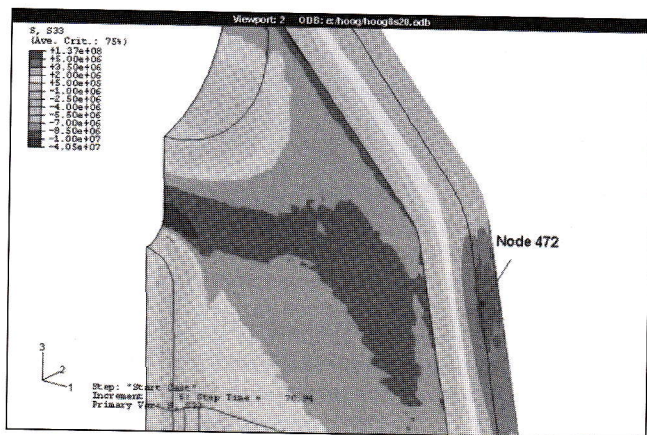


Fig. 4 - Stress evaluation of thin slab nozzle

Fig. 4 - Valutazione degli sforzi termici applicati su un o scaricatore per brame sottili.

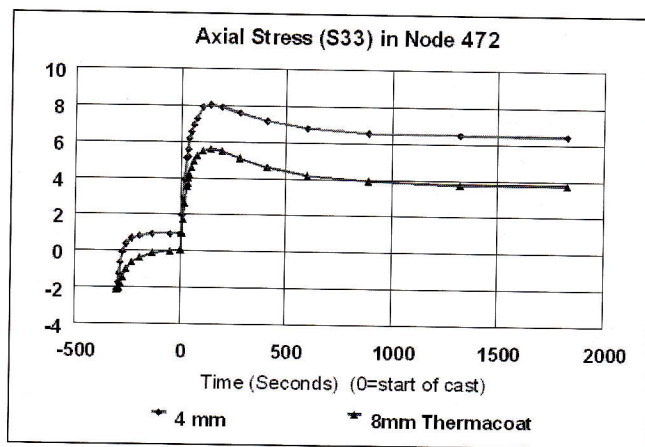


Fig. 5 - Local stress on narrow face

Fig. 5 - Sforzo locale applicato sulle facce strette di uno scaricatore per brame sottili.

with appropriate products properties determination. The effects on refractory material and design are highly depending on operating conditions. In other word, a refractory product can not be ranked in terms of thermal shock resistance but for one given thermal shock situation in a given application.

Thermal stress situation have to be carefully analyzed in order to determine the major cause of failure: material properties or design. The optimization of refractory component consistency as steel casting efficiency are depending on the model accuracy.

An example of nozzle for thin slab caster is shown in figure 4. The view represent a quarter of the total pieces cut by the 2 symmetric planes.

The maximum stress is localize on the narrow face of the nozzle where the thermal shock cracking is usually observed. The analysis of the stress during the transient start up of the cast show that the maximum stress is developed a couple of minute after steel casting start and that the stress developed during preheating in much lower.

As a consequence the increase of thickness of the insulation layer (Thermacoat) has reduced significantly the stress level and reduce the cracking tendency.

### STEEL FLOW CONTROL OPTIMIZATION

In order to better understand steel flow characteristics during casting and steel flow consequences on refractory components, specific fluido-dynamic models have been developed with dedicated features (Numeca International).

The main features investigated are for example:

- Specific meshing refinement at refractory interface to capture physical parameters at refractory interface.
- Thermal exchange between refractory and steel to better evaluate temperature loss in steel as well as thermal gradient in refractory
- Chemical interaction with refractory interface and contamination diffusion in steel flow.

The mesh refinement capability is illustrated in figure 6 representing the steel flow regulation between a tundish stopper and a submerged nozzle.

The noticeable high speed at the regulation area justify the occurrence of severe corrosion phenomena at this location. Secondly the extraction from the steel flow results of the pressure at refractory surface (figure 7) explain the strong degassing of refractory observed in this area.

Such CFD tools are now routinely used, not only to improve steel flow but also to optimize refractory design and composition.

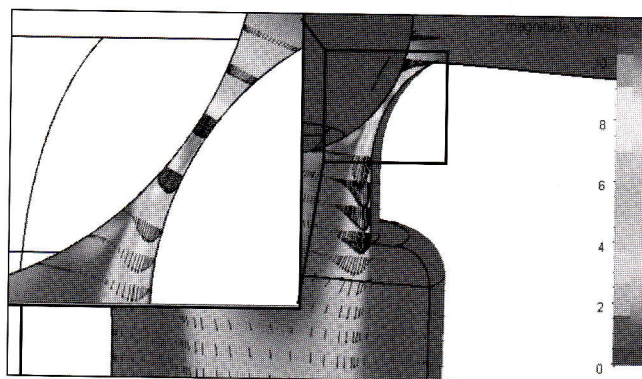


Fig. 6 - Calculated steel flow at stopper regulation point.

Fig. 6 - Flusso acciaio calcolato nella zona di regolazione del tampone.

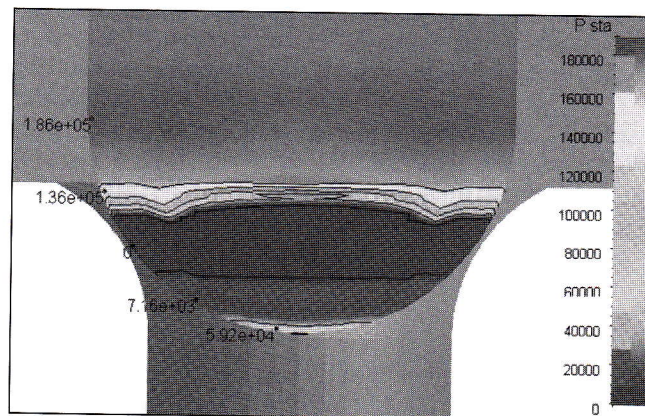


Fig. 7 - Pressure at refractory surface on tundish stopper.

Fig. 7 - Valutazione della pressione esercitata dall'acciaio sulla punta di un tampone panier.

### CONCLUSION

Increasing demands for steel quality and continuous casting productivity require new approaches in terms of refractory components development. Advanced refractory design is achieved by coupling dedicated thermo-chemical and thermo-mechanical models with fluido-dynamic simulations. When appropriate material behavior at operating temperatures is experimentally demonstrated and validated, models results provide innovative solutions for refractory components optimization. Those new approaches, combined with empirical field experience, are necessary to improve current and future steel continuous casting process.

**DISEGNO AVANZATO PER I REFRATTARI  
DI COLATA CONTINUA**

*Nuovi strumenti di disegno sono stati sviluppati per ottimizzare i refrattari di Colata Continua con l'obiettivo di aumentare la produttività della macchina e migliorare la qualità del prodotto finito. Questi strumenti permettono di prevedere la reazione chimica tra acciaio e refrattario e, da questa, l'evoluzione della composizione chimica dell'acciaio, il deposito di impurità, la corrosione. Sono stati sviluppati dei modelli fluidodinamici specifici per*

*meglio valutare i parametri fisici dei refrattari ed ottimizzare il controllo del flusso acciaio. Il modello fluidodinamico realizzato al computer, accoppiato con lo studio dell'interazione chimica tra acciaio e refrattario, può essere utilizzato per simulare l'evoluzione chimica dell'acciaio.*

*Questi due differenti approcci, che portano a modifiche della geometria e dei materiali, sono completati da un'analisi degli sforzi termici realizzata con il metodo degli Elementi Finiti: questo permette di valutare le proprietà fisiche dei refrattari all'aumentare della temperatura allo scopo di migliorare la resistenza dei materiali agli sbalzi termici.*