Mould Powders

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Mould Powders

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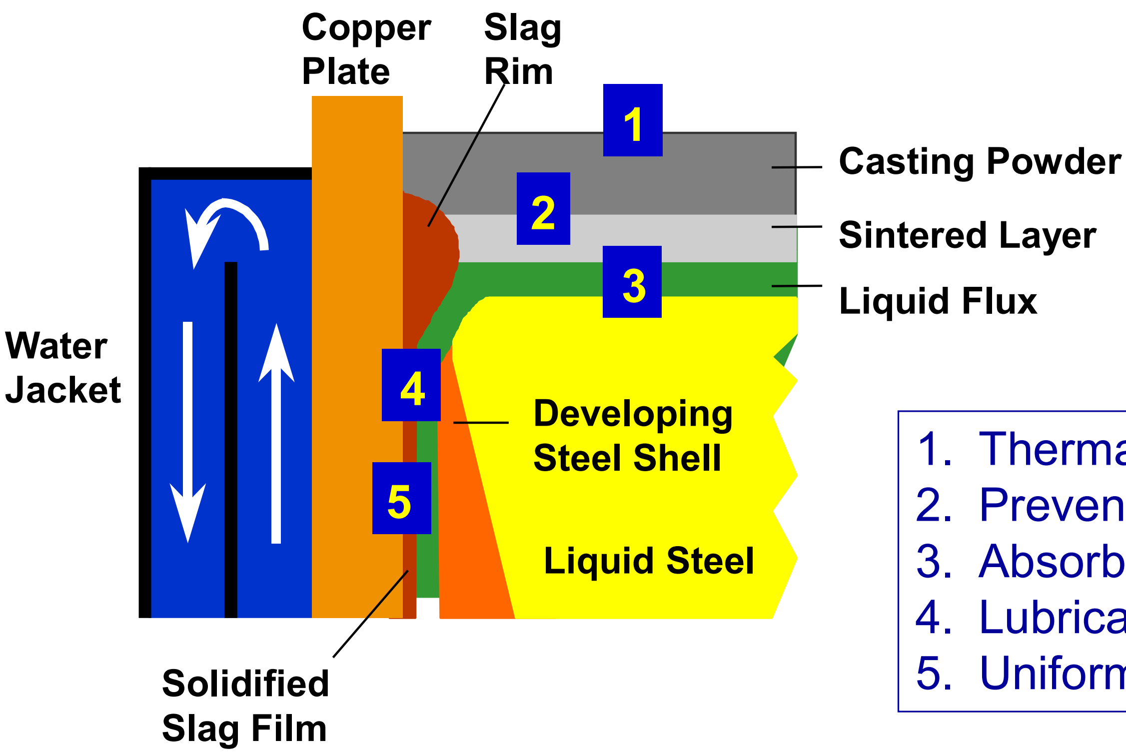
Introduction

European Funded Projects involving Mould Powders

Acronym	Title	Year	Report Number
7210-PR/273	Mould powder consumption, melting and lubrication and their effects on mould heat transfer and subsequent surface quality of continuously cast slab	2005	EUR 21907
FOMTM,	Application of fibre optical thermal monitoring at CC billet mould for improved product quality, Report number,	2007	EUR 28466
FLUXFLOW	Enhanced steel product quality & productivity by improved flux performance in the mould through optimising in the multiphase flow conditions & special regard to melting & entrapment	2008	EUR 23182
PRECIPITATION	Precipitation behaviour of micro-alloyed steels during solidification and cooling,	2010	EUR 24024
SLAGFILMOWL	Optimising slag film properties and determination of operational windows for lubrification, mould heat transfer and shell formation	2011	EUR 24988
LSSEMIQUAL,	Reduction in surface cracking in as cast low sulphur and calcium treated steels, Report number,	2013	EUR 25885
LUBRIMOULD,	Identification of optimal mould lubrification conditions through an innovative hot and cold simulation method, Report number,	2013	EUR 26173
TRANSIENT,	Effect of transients on quality of continuously cast product, Report Number,	2014	EUR 26399
INNOSOLID	Investigation of innovative methods for solidification control of liquid steel in the mould	2019	EUR 29549
NNEWFLUX	Non-Newtonian mould fluxes - a smart viscosity response to enhancing production flexibility of steel grades prone to entrapment	Ongoing	Ongoing
OPTILOCALHT	Optimisation of Local Heat Transfer in the CC Mould for Casting Challenging and Innovative Steel Grades	Ongoing	Ongoing
RealTimeCastSupport	Embedded real-time analysis of continuous casting for machine-supported quality optimisation	Ongoing	Ongoing

Introduction

Function of Mould Powder

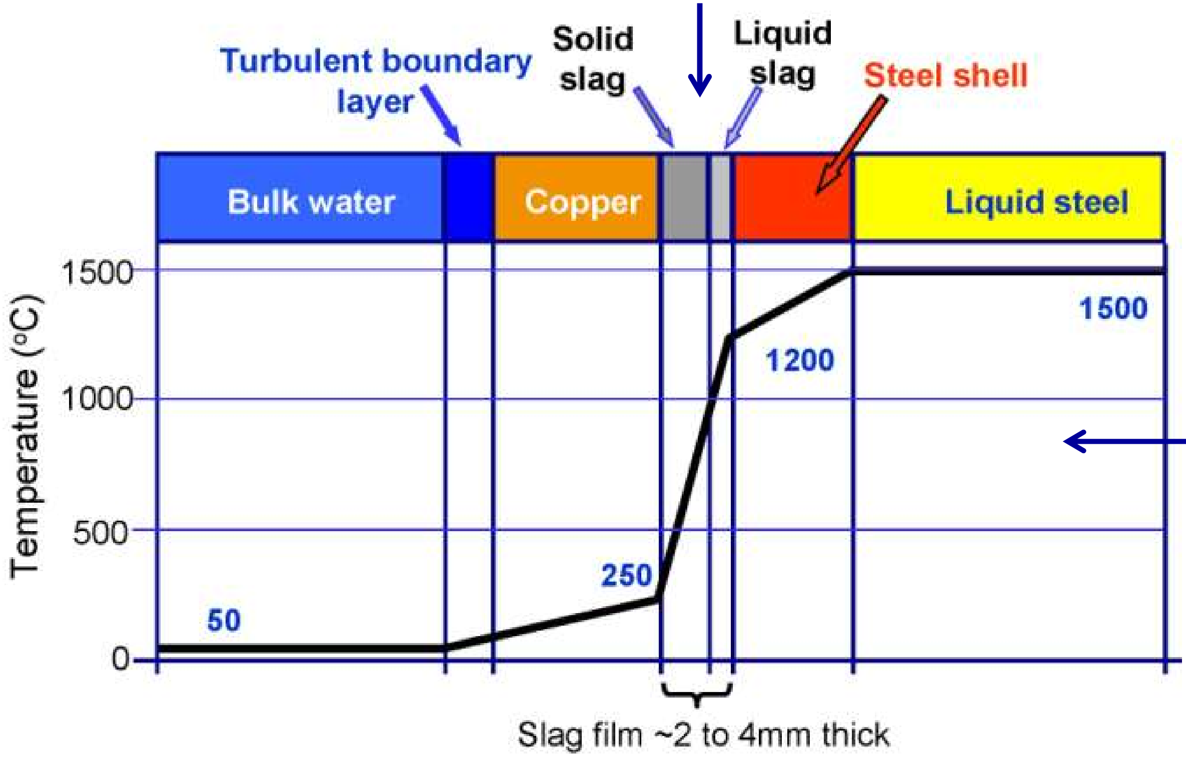


1. Thermal insulation
2. Prevent reoxidation
3. Absorb inclusions
4. Lubrication
5. Uniform heat transfer

Introduction

Function of Mould Powder - Mould Flux Heat Transfer

The viscosity and solidification characteristics of the mould powder slag (glassy or crystalline) have a great influence on heat transfer



Differing steel grades require different heat transfer rates for optimum surface quality and security against breakouts

Physical Properties

To understand how a mould flux will behave during casting it is important to understand the physico-chemical properties

- Viscosity (η) - A measure of how resistant a liquid is to movement.
- Liquidus Temperature (Tliq) – Temperature at which the flux is completely liquid.
- Solidification Temperature (Tsol) – Temperature at which the flux is fully solid.
- Break Temperature (Tbr) - Temperature at which there is a significant change in the viscosity usually associated with the start of crystallisation.

These properties can be measured in the laboratory using a range of techniques such as heating microscope, rotational viscometry and simultaneous thermal analysis (STA).

Consumption Rate

7210-PR/273 - Mould powder consumption, melting and lubrication

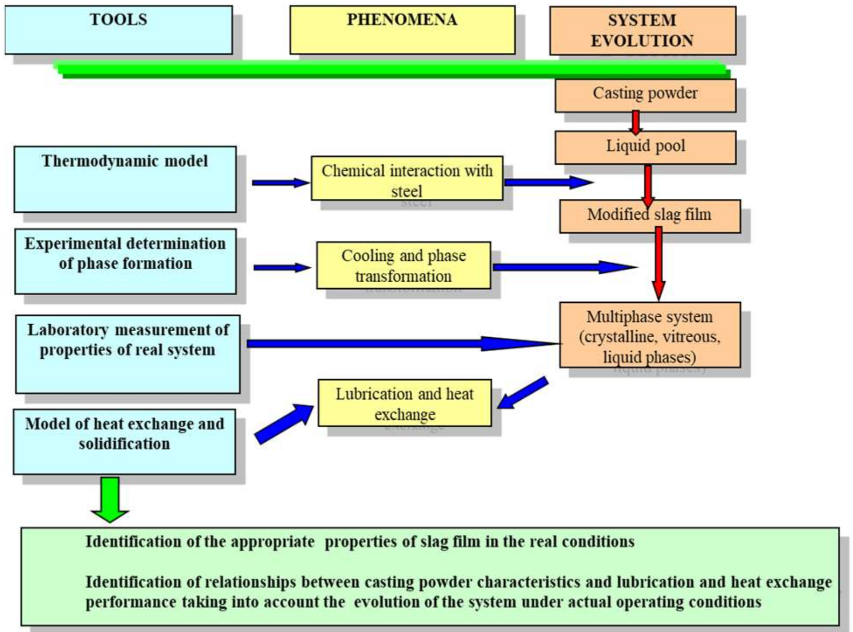
- Mould powder consumption is heavily dependent on section size and reduces with increased size being cast. Consumption rate can be normalised for comparison by quoting kg/unit area to normalise the section size or kg/tonne cast to normalise section size and casting speed.
- The most direct influence on powder consumption was casting speed although a secondary correlation was established with carbon content in the steel and more significantly carbon equivalent.
- Other parameters such as superheat, argon injection, SEN immersion depth, surface to volume ratio of the mould, Ca and Al content of the steel and tensile strength of steel were investigated, but no significant correlations were found
- The consumption rates calculated were used to control a new automated powder feeder with promising results. However, more work was needed to optimise the system.
- Models for predicting flux consumption were developed which gave good agreement with measured values. The model can be used to specify the melting range and viscosity required in a mould powder.
- The effect of oscillation strategy on powder consumption, slag pool depth and thickness of the slag film were investigated via laboratory simulation.
- Following tests and modification, predicted shell thickness was in good agreement with the measured values and the correlation between measured slag layer thickness and the values predicted from powder consumption were greatly improved.

Consumption Rate

SLAGFILMOWL

To improve the surface and sub-surface quality of continuously cast carbon and stainless steel semis by:

- Optimisation of the mould-strand slag films
- Definition of operational windows for lubrication and mould heat transfer,
- Development of an understanding of interaction between mould and surface quality



- Powder Consumption is closely linked with the lubrication properties of a mould powder. The depth of the flux pool increases with the casting speed and melting rate.
- Considering billet/mould friction with the thermocouples in the instrumented mould, it was possible to observe slag rim formation.
- Mould powders, slag rims and slag were characterized in the laboratories and used in modelling to understand the relationship between powder composition and behaviour.
- The key properties for high-speed billet casting were viscosity and melting rate.
- Chemical interaction between slag film and steel was studied by analysing samples from industrial casters.
- A model was developed to predict the chemical variation in the slag composition.
- Steel metallurgy greatly affects the chemical composition of the slag from mould powder. This has been supported by observations in other projects such as ***INNOSOLID***.

Composition of Mould Powders

Standard mould powders are a mixture of glassy components and basic oxides
They have a base composition made up of:
Calcium oxide (CaO) and Silicon dioxide (SiO_2)

Plus other oxides for example:
Magnesium (MgO), Aluminium (Al_2O_3), Sodium (Na_2O), Potassium (K_2O), Titanium (TiO_2), Zirconium (ZrO_2), Boron (B_2O_3), Lithium (Li_20), Manganese (MnO)

To this is added **fluoride** and **carbon**

Fluoride acts as a fluidising agent and to promote crystallisation of cuspidine (3CaO.2SiO2.CaF2)
The degree of crystallinity has a significant effect on the heat transfer properties.

Carbon is added to control the melting rate.

The amount, particle size and form of carbon added has an influence on the melting rate.

More carbon will reduce the rate, also different types of carbon will react at different rates.

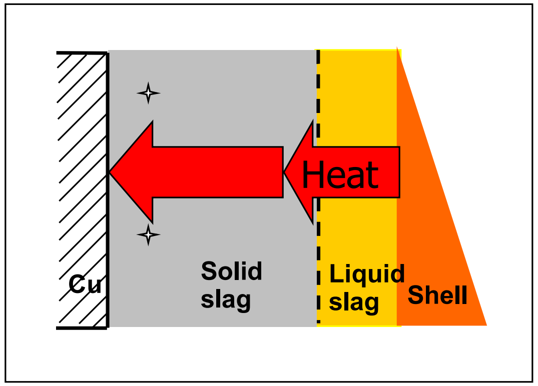
Heat Transfer

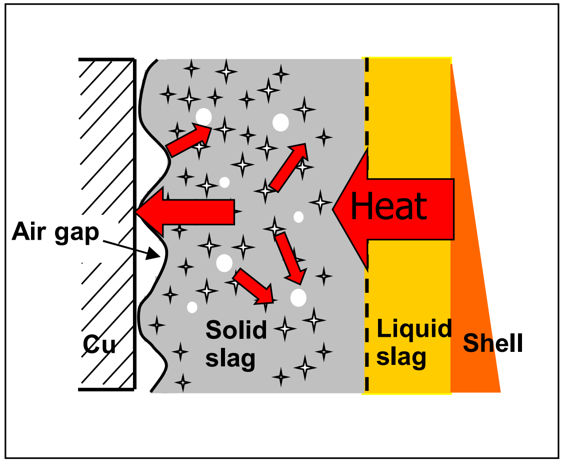
Prediction of mould powder crystallinity

Heat transfer through the flux is controlled by thickness of the layers and the amount of crystalline slag. Heat transfer is reduced by the scattering effect of the crystal boundaries.

As the liquid slag cools, crystallisation begins at the break temperature.

The relationships between glass/crystalline ratio and thermal diffusivity was investigated in ***7210-PR/273*** and were used to develop a mould heat flux model. It was found that the thermal diffusivity of the slag film could be predicted from the glass/crystalline ratio.





In ***SLAGFILMOWL*** the influence of basicity on crystallisation rate was shown and its impact on film thickness which in turn regulates the heat flux - the greater the degree of crystallisation the greater the film thickness.

Many regard basicity (Lime/Silica Ratio) as a measure of the potential degree of crystallinity in the flux layer. When specifying a powder, the basicity can be used as an indication of the likely thermal resistance in practice.

However, the ***LUBRIMOULD*** project suggested that the depolymerisation index (NBO/T) is a better parameter for evaluation of the thermal properties. The index NBO/T is a calculated parameter based on the chemical composition of the casting powder.

Composition of Mould Powders

FLUXFLOW

FLUXFLOW looked to enhanced steel product quality and productivity through improved flux performance

For stainless steel, a higher free C content increases the occurrence of defects due to the influence of carbon on melting rate and thus on liquid flux layer thickness. It was also seen that the thickness of the flux layer depends strongly on the powder used. This can lead to entrapment of powder which has a great impact on the occurrence of defects remaining on the steel surface.

The recommended Carbon content was found to be below a critical value: 5% for stainless and 20% for carbon steels.

For long product the powder properties of most concern were the viscosity and the melting rate which should be properly coupled with casting speed.

- The lower the steel carbon content, the higher the shell shrinkage which requires greater liquid slag production. To achieve that, low values of free carbon were used to provide a higher melting rate and a homogeneous slag film between the mould and the solidified shell.
- For the higher carbon grades, the mould flux viscosity should be lower to improve liquid flux infiltration between billet and mould.

Composition of Mould Powders

Special Mould Powders - Low F/LowC

Research into novel powders to overcome specific issues has increased with a significant effort going into carbon and fluorine-free powders.

When casting low or ultra-low carbon steel grades pickup of carbon from the mould powder can be a problem which can lead to surface defect issues. Low carbon mould powders help to prevent this, but without enough carbon in the mould powder, the melting rate becomes too high and can cause slag rim issues.

The use of fluorides in mould powders to control crystallinity has significant negative aspects:

- Fluorides react with cooling water to form hydrogen fluoride which is a potential health and safety issues for operators.
- By-products such as hydrofluoric acid lead to issues with corrosion in the casting machine.

There are ongoing projects such as ***RealTimeCastSupport*** looking at the selection of suitable low fluorine or fluorine-free powders. The main thrust is the replacement of the fluorine bearing components with an alternative such as Na_2O or B_2O_3. In trials these have been shown to perform in a similar manner to conventional powders for specific steel grades.

There is an associated benefit that erosion of refractory at the slag layer seemed to be less than with conventional powders.

Powder feeding

Mould powder feeding is critical to performance of mould powders in terms of consistency and repeatability of the casting process.

Manual powder feed performed by operators is the most basic method. This results in a batch feed process with poor consistency.

A constant gravity feed mechanism is simple and crude. This still relies on the experience and attention of an operator and tends to result in a very thick powder cover.

Powder application can be controlled using a variable rate feeder based on a model or equation taken from previous plant data. Feed rate is then set using casting parameters but must still be monitored and potentially adjusted by an operator.

The ideal for consistent and reliable feed is closed loop control. A number of systems are available with techniques including radiological, optical or laser-based powder thickness measurement to control feed rate.

Powder feed

During the ***LUBRIMOULD*** project, the effect of mould powder addition on lubrication conditions was investigated.

Trials showed variation in both thermocouple and mould friction as a consequence of the mould powder addition. The friction shows a sudden drop after the addition that is due to the return to the optimal lubrication conditions. Sudden changes of mould friction can be linked with lubrication problems and subsequent product defects.

For correct lubrication and infiltration of casting powder it is important to avoid the formation of large slag rims which can close the opening between the steel and the mould, preventing flow of liquid flux and inhibit lubrication, possibly leading to a sticker breakout. A new mould powder addition technique was proposed based on small and successive additions of mould powder to reduce the build-up of large slag rims.

***TRANSIENT* -** Plant trials on a slab caster showed asymmetric mould powder feeding could cause mould powder break up which was significantly improved using automatic powder feeders and granulated mould powder. Permanent installation of mould powder feeders and use of granulated mould powder resulted in an 8% reduction in mould powder consumption.

Modelling

During European projects many models have been developed relating to mould powders. These have included:

- Prediction of flux properties from powder composition
- Evolution of the slag composition due to contact with liquid steel
- Formation of liquid flux layers
- Flux layer thickness
- Flux flow in moulds
- Flux consumption
- Heat transfer through flux layers
- Liquid fraction in the mould
- Stresses in the solidified shell and crack formation

These projects have demonstrated that modelling can be used to experiment with new conditions in terms of modification of the casting parameters and powders.

New and more powerful tools for powder selection have been developed using numerical and computational modelling. Over time, as would be expected with developing digital technologies and techniques, this has become more complex.

The most complex models are where different elements and separate models are being linked to create an overall simulation of the process including not just the mould flux but the entire steel solidification process.

For example the model produced in the ***LUBRIMOULD*** project where the output of the CSM layer thickness model which simulates shell formation and heat transfer was fed into the KIMAB heat flux model. This allowed estimation of the thickness of the shell at the exit of the mould and visualisation of flow pattern in melt and mould slag.

Novel Techniques

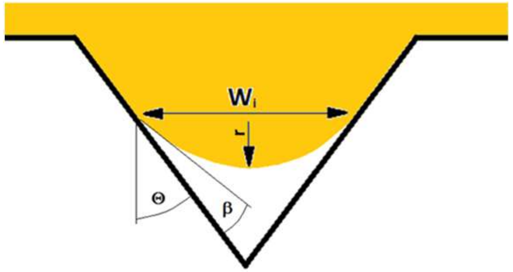
INNOSOLID

The aim of the project was to improve product quality using innovative concepts for an optimized heat transfer for slab casting. The structured copper plate concept (*SCPC*) had a strong mould powder element.

A surface profile was applied to the mould copper surface. The profile allows the solidified slag layer to thicken locally increasing the thermal resistance in the grooved area.

The optimum surface profile was selected by numerical simulation and physical laboratory trials.

There was a significant influence of the viscosity, i.e. penetration into the grooves was increased with decreasing viscosity.



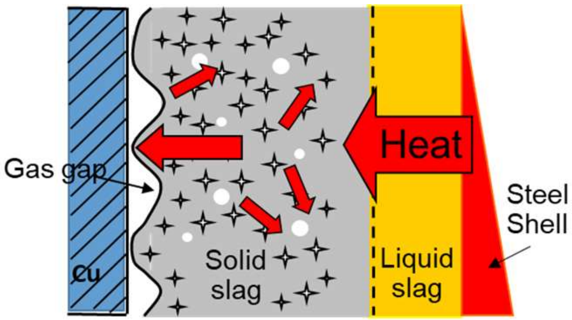
Trials were carried out on the mould of a pilot caster at Tata Steel. There was a clear improvement of surface quality linked with the mould surface profiling for peritectic grade casts.
It was not possible during the timescale of the project to move to industrial trials.

Ongoing Developments

Intumescent mould coating

Two ongoing RFCS projects are looking into innovative techniques to control heat flux.

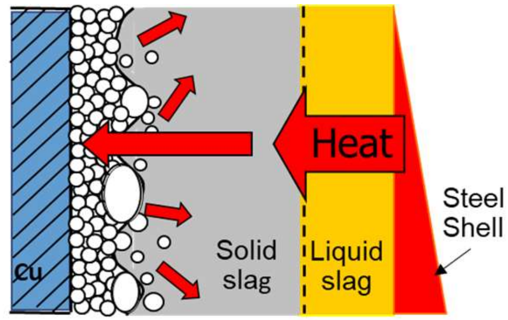
These include an intumescent mould coating which forms a layer sitting between the mould surface and the mould slag. This layer reacts with the molten steel to form controlled porosity between the solid slag and mould plate.



Fluoride-based phases (✦) have been **key to slowing shell cooling** rate for best surface quality for peritectic steels

In the second technique an increased number of iron particles are incorporated into the flux to reduce heat transfer without changing the flux composition.

These techniques have been shown to contribute to reduction of heat transfer by the scattering of radiation.



Shown that can achieve required slow cooling with **intumescent coating** instead

Both these techniques are being investigated in ***OPTILOCALHT*** and the intumescent coatings in ***RealTimeCastSupport***

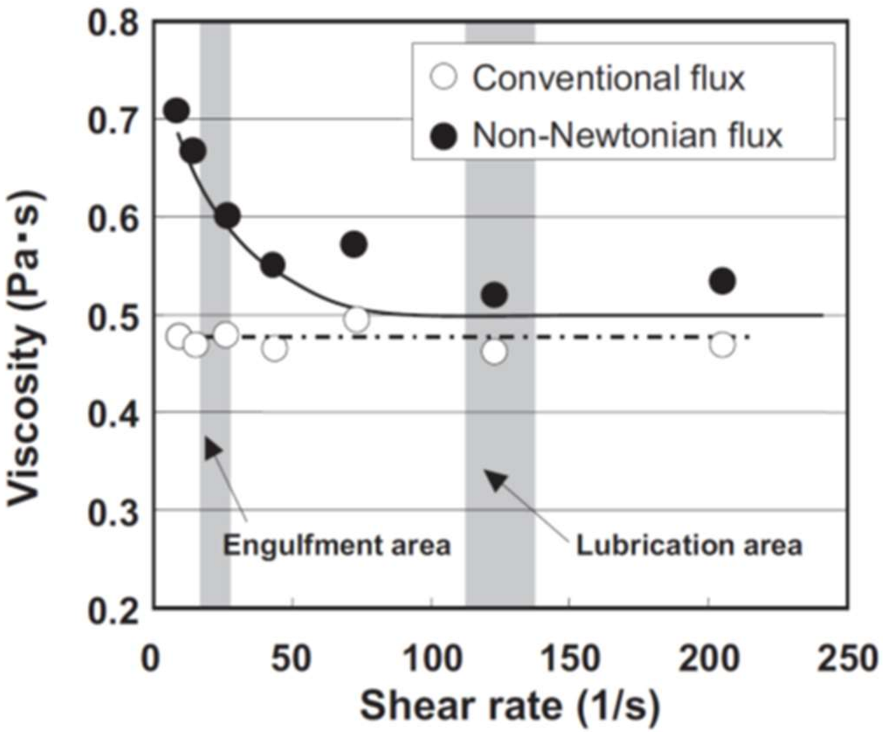
Ongoing Developments

NNEWFLUX

Non-Newtonian mould fluxes - a smart viscosity response to enhancing production flexibility of steel grades prone to entrapment

The project proposes the use of Non-Newtonian mould fluxes which have a viscosity that varies with the shear force applied. This flux could be used to reduce the occurrence of slag entrapment.

Non-Newtonian flux can have a high viscosity at the meniscus reducing entrapment and low viscosity between the stand and mould where lubrication is required.



Discussion

Almost every project has included a benchmarking element where data is gathered from commercial casters including monitoring and sampling of powders in use. This data is essential for the generation and validation of simulations.

Every project developed a database of powder and plant performance data. These tend to be project specific and there could be some benefit from compiling these separate resources into a unified data source. This would require centralised coordination to ensure objectivity and independence.

Conclusions

- Mould powders are essential to crack free casting and there has been a number of projects dedicated in whole or part to the study of mould powder behaviour.
- The majority of cracking is initiated in the mould during initial solidification. The performance of mould powders has a significant effect on initial solidification.
- The composition of a mould powder can alter during casting particularly the alumina content as alumina inclusions are absorbed by the liquid flux changing the flux properties.
- Selecting a mould powder is a complex issue. New and more powerful tools for powder selection developed in these projects help with the selection process.
- Standard practice in steel plants is to use the basicity index as a measure of the potential degree of crystallinity hence thermal resistance in the flux layer. However, the depolymerisation index (NBO/T) is a better parameter for evaluation of the flux behaviour.
- Best practice for powder feed is consistency of application either by applying the powder 'little and often' or using automated continuous feed.

Future Developments

The Way Forward

- Creation of a unified database for mould powders.
- Project to compare and contrast techniques used in modelling. Production of a unified comprehensive model to predict mould powder properties, how mould flux evolves during casting and interaction with the casting process.
- Techniques developed for local control of heat flux at the meniscus developed during the ***INNOSOLID*** project have potential for future development.

Thank you for your attention.

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