Mould Powder Benchmarking

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Introduction

Mould powders are a fundamental element of continuous casting and critical in the production of high-quality, defect free, semi finished steel product. Powders do not all behave the same on all casters.

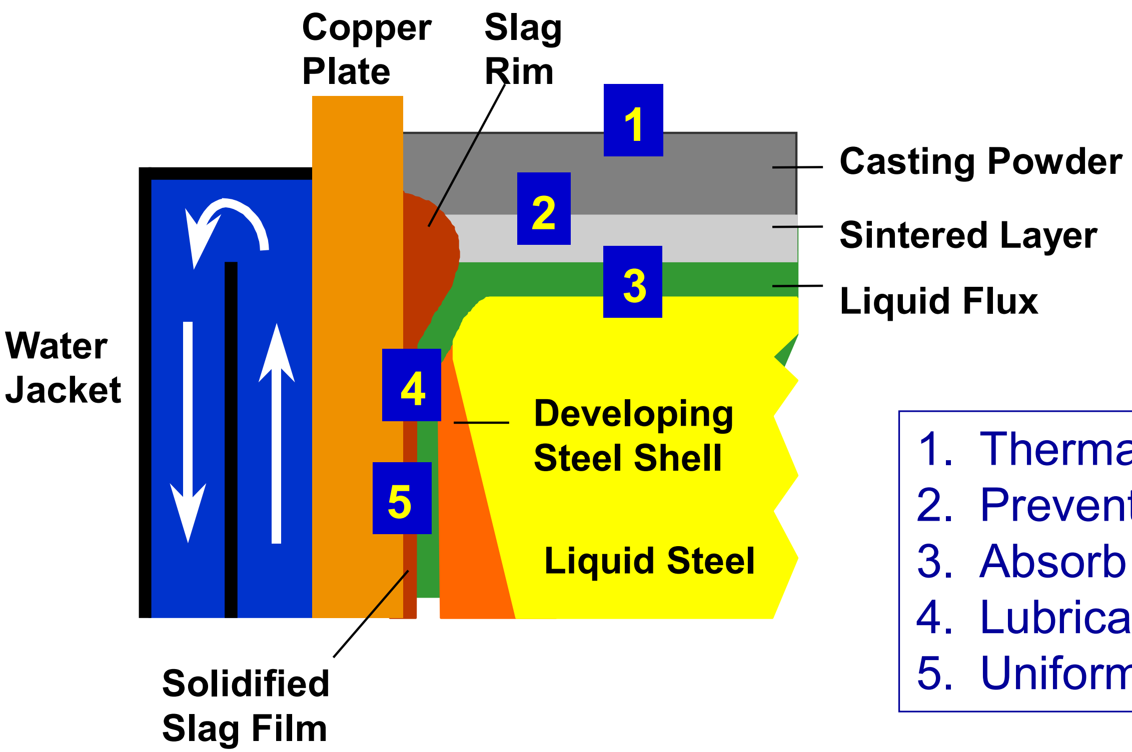
In this webinar we will talk about a number of techniques that have been used in various projects to assess or measure the performance of mould powders during casting.

This will include:

- Brief introduction to the function of mould powders
- Laboratory techniques to quantify properties
- On-line measuring and sampling techniques

Introduction

Function of Mould Powder



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

Laboratory Techniques

Physical Properties

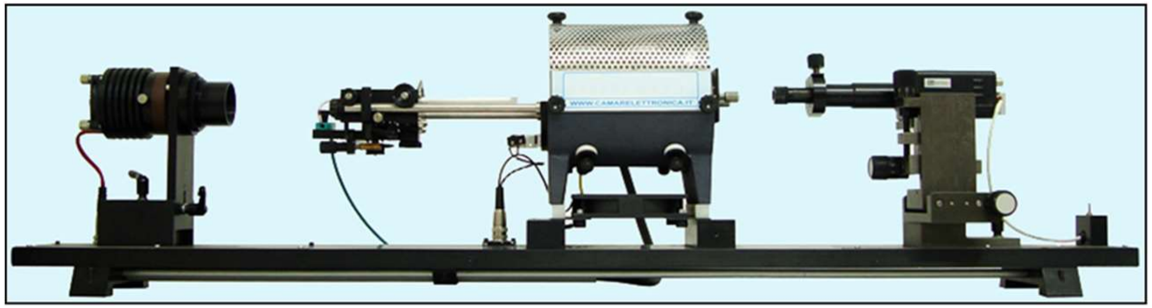
To understand how a mould flux will behave during casting it is important to understand the physico-chemical properties

- Viscosity (η) - A measure of how resistant a liquid is to movement.
- Liquidus Temperature (Tliq) – Temperature at which the flux is completely liquid.
- Solidus Temperature (Tsol) – Temperature at which the flux begins to solidify during cooling.
- 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).

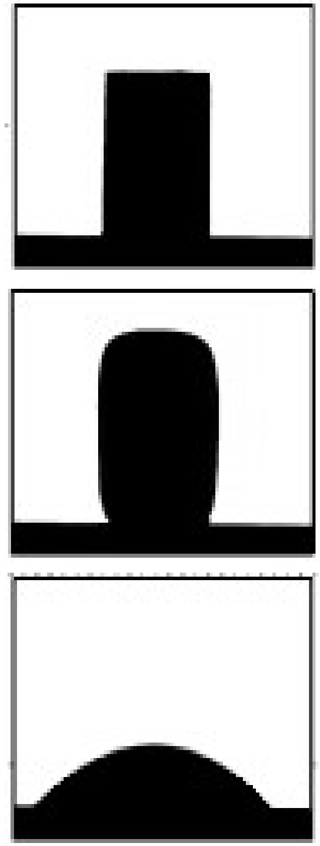
Laboratory Techniques

Heating Microscope



A heating microscope consists of a horizontal tube furnace that slowly heats a small pellet of mould flux to identify the thermal transition points: **sintering**, **softening**, **melting** and **fluidity** according to the standard DIN 51730.

In addition, the heating microscope can measure the **contact angle** of the liquid mould flux against the substrate to calculate **interfacial tension**. Interfacial tension is important during casting, since it can affect slag entrapment and slag infiltration (related to lubrication).

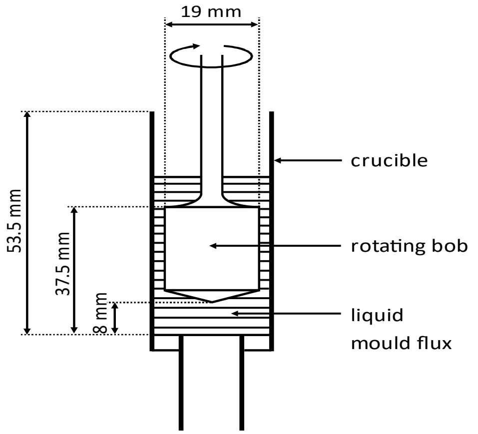


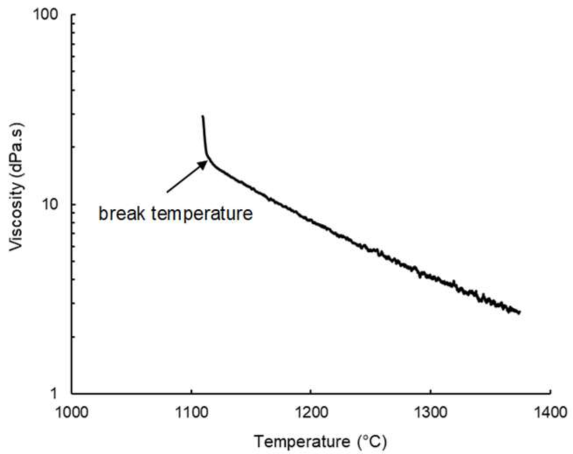
Laboratory Techniques

Rotational Viscometer

The rotational viscometry technique allows the **viscosity** of a mould flux to be measured over a temperature range.

A crucible filled with mould flux is heated in a furnace to above the melting point of the flux. A spindle is then lowered into the melt and spins at a constant speed. By measuring the torque on the motor, the viscosity can be measured.





During cooling, the **break temperature** can be identified from a sudden increase in viscosity. This is due to solid particles precipitating in the melt. If no break temperature occurs, a super-cooled glass is formed.

The break temperature determines the thickness of the solid and liquid flux layers in the mould-strand gap, relating to heat flux and lubrication respectively.

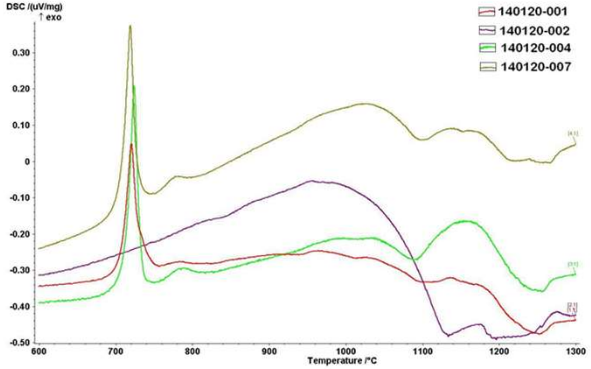
Laboratory Techniques

Simultaneous Thermal Analysis (STA)

Simultaneous thermal analysis consists of both thermogravimetry and differential thermal analysis (or differential scanning calorimetry). This technique can be used to characterise the various thermal stages of a mould flux during heating and then cooling.

Characteristics that can be identified include:

- **Moisture content**
- **Carbonate content**
- **Carbon content**
- **Melting range**
- **Solidification temperature**



The carbonate and carbon content is important as it determines the melting rate of the powder. The melting rate should be controlled so that it matches the powder consumption rate. The melting range will be similar to the melting transition points identified with the heating microscope. The solidification temperature will quite often be different to the melting range since:

a) the phases present in the mix of raw materials will be different to what precipitates from the melt and
b) super-cooling will occur during initial crystal grain growth.

On-line measuring and sampling techniques

In-mould observations

It is generally accepted that over 90% of concast defects originate at, or within, 25 mm of the meniscus. Hence the conditions within the mould at the meniscus have a strong effect on surface quality. For good initiation of shell growth, stability is important, but there needs to be sufficient movement at the surface to ensure the mould powder melting rate is high enough to replenish the liquid slag pool.

In-mould observation is a tool as part of the benchmarking of powder performance, including:

- **Turbulence and movement of the meniscus**
- **Obvious flow and direction**
- **Cross flow at end plates**
- **Standing waves**
- **Travelling waves**
- **Areas of high powder consumption**
- **Exposed steel**
- **Argon bubbles**

On-line measuring and sampling techniques

Liquid slag sampling

The composition of mould flux has been shown to evolve during casting. This change in composition is due to pick up of inclusions from the mould where they are carried to the surface and are captured and absorbed by the liquid flux. This can be linked to changes in the viscosity of the liquid flux. The amount of pick up is linked to steel composition.

Inclusion	Effect	Results
Al2O3 particularly aluminium killed steels containing ~ 1% aluminium	Can increase slag viscosity, basicity and melting temperature, reducing lubrication	Poor surface quality and sticking in the mould
MnO particularly in high manganese steels with high oxygen contents	Reduces viscosity and solidification temperature	Depressions and cracks in sensitive steel grades

To monitor the composition changes, samples can be taken from the mould during casting. A simple technique that has been applied successfully uses a stainless steel ladle or spoon to remove an amount of liquid flux from the mould. The samples are poured onto an inert surface to chill.

On-line measuring and sampling techniques

Liquid slag sampling

In this example taken from an RFCS project, a significant increase can be seen in both the Alumina and Manganese oxide content of the slag during casting.

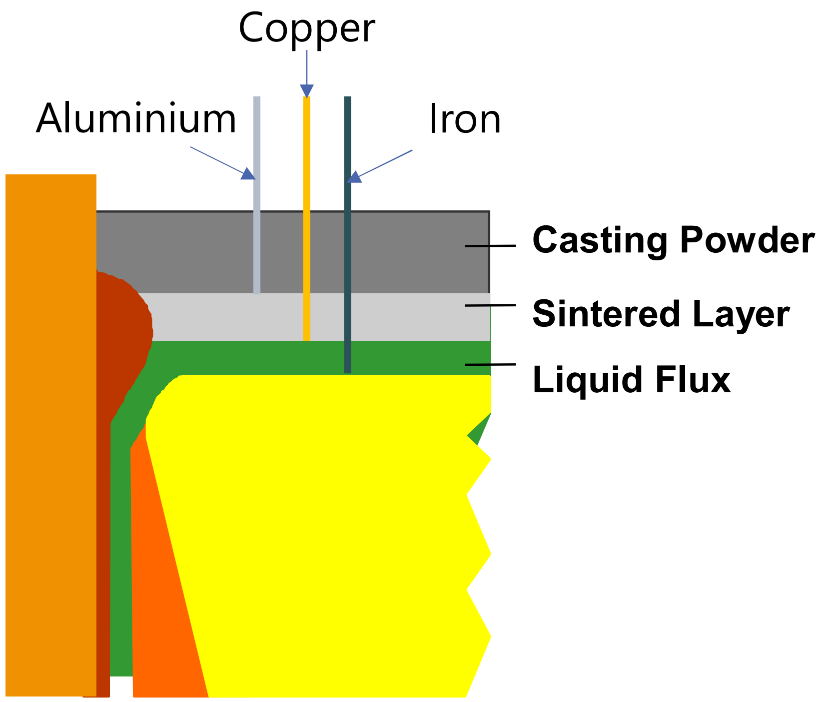
	Fe	CaO	SiO2	MnO	Al2O3	MgO	P2O5	K2O	TiO2	Na2O	S	Viscosity
	%	%	%	%	%	%	%	%	%	%	%	dPa s
Raw Powder	0.47*	42.4	35.2	0.0	3.6	2.3	0.75	0.25	0.12	8.4*	0.64*	0.82
Ladle 1	0.85*	40.3	33	0.9	7.1	2.4	0.25	0.29	0.13	9.0*	0.28	1.27
Ladle 2	0.66*	41.4	32.7	1	6.4	2.5	0.03*	0.29	0.13	8.8*	0.2	1.51

These samples were taken towards the end on the first and second ladle in a casting sequence of a peritectic grade. The increase in the alumina and manganese oxide can be seen to lead to the viscosity of the liquid flux almost doubling.

On-line measuring and sampling techniques

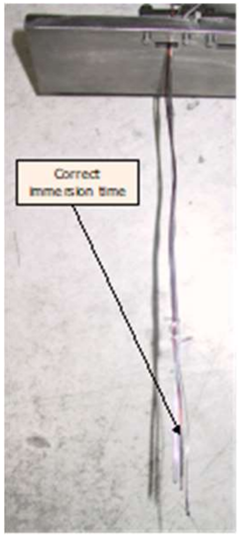
Flux Layer Measurement

For good surface quality, good mould lubrication is essential, and for good lubrication, it is generally recommended that the liquid slag pool depth is greater than the mould oscillation stroke length.



Two main techniques have been developed to measure the thickness of the mould powder/flux layers on the casting mould during RFCS projects. The 3 wire and the plate dip method.

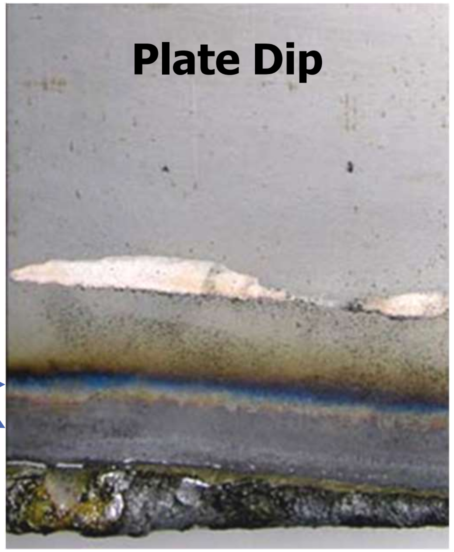
The 3 wire method uses an iron, a copper and an aluminium wire usually dipped into the mould as a bundle. The melting point of each is such that they melt off in the liquid steel, liquid flux and the sintered layers



On-line measuring and sampling techniques

Flux Layer Measurement

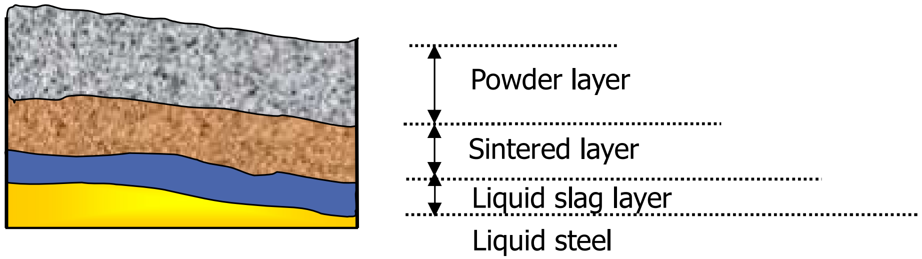
The plate dip technique - A steel plate is dipped into the mould and the discolouration of the lines on the plate and materials adhering correspond to the different layers of material that the plate was in contact with. This allows the thickness of each layer, including the liquid slag pool, to be calculated.



Temper effects

In project 7210-PR/273, a comparative test showed that the most reliable test results seemed to be obtained using 0.35mm dipped for a period of 3 seconds.

Layers in mould



On-line measuring and sampling techniques

Flux Layer Measurement

"Nail Board" Tests

The wire dip technique has been expanded to form a "nail board" where an array of 3-wire dips covering a relatively large area in the mould can be used to give a surface profile. This gives an indication of how the layers vary in thickness over an area and generate average film thicknesses.

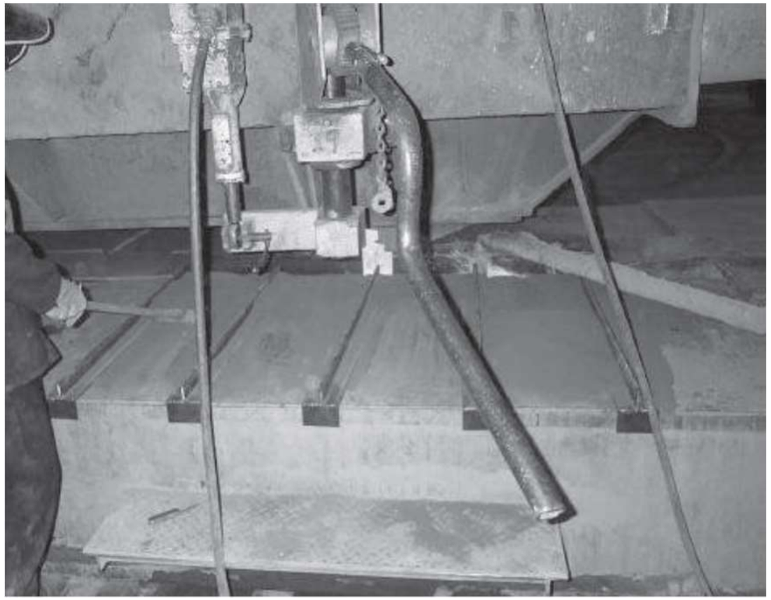
These nail boards can also be used to map the profile of phenomena like standing surface waves.

On-line measuring and sampling techniques

Mould powder consumption measurements

Where manual mould powder application is used on slab casters it is possible to investigate variation in where powder is being consumed across the mould by dividing the mould canopy into sections and pushing known quantities of mould powder when required.

This technique has been used to investigate the difference in mould powder consumption between the edge pates and SEN. Uneven consumption can be linked to mould flow conditions such as asymmetry



On-line measuring and sampling techniques

Mould Friction

It is possible to use mould oscillation to monitor the friction generated between the mould and solidifying strand.

When using hydraulic oscillators, the friction in the mould can be calculated from the hydraulic pressures. With conventional mechanical oscillators direct measurement is not possible but the oscillator current can give some insight into what is happening in the mould.

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

On-line measuring and sampling techniques

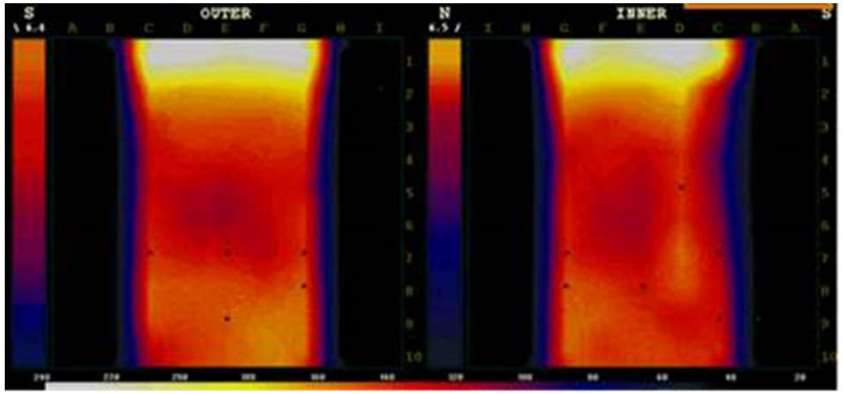
Mould Thermal Monitoring

Mould thermal monitoring, or MTM, is a system originally designed to detect stickers in the mould as a method of early detection of potential breakouts.

However the thermocouple arrays can be used to assess mould flux performance by measuring heat transfer locally in the mould and highlight where the distribution of heat flux is uneven.

Variability of MTM temperatures with time increases during periods of poor mould powder performance, which can lead to surface defects.

Recent work has applied large arrays of fibre optic temperature measurement in mould plates to generate detailed thermal maps.



Summary

A number of techniques are available to benchmark the performance of mould powders.

Physical properties – Lab measurements

- Hot stage camera
- Viscometer
- Simultaneous Thermal Analysis (STA)

Online measurements

- In-Mould observation
- Slag sampling from mould - composition evolution
- Flux layer measurement
- Consumption rate
- Mould friction
- Mould Thermal Monitoring

Thank you for your attention.

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