The Elimination of Defects by Mould Flux Adjustment

D. Eckhardt

INTRODUCTION

Defects and especially surface defects of continuously cast steel are strongly related to mould powders and their application. Hence, customers expect from their suppliers the elimination of defects by appropriate customizing of mould fluxes. The defect types of continuously cast products are manifold. Aim of this paper is to highlight the potential and elementary chances of surface quality improvement by mould fluxes adjustment, but also their limitations.

MOULD FLUX FUNCTIONS

In principle, mould fluxes are powdery or granulated. As illustrated in Fig. 1, mould fluxes have these functions[1]): The unmelted top layer in the mould must provide an effective thermal insulation of the steel meniscus. The liquid slag layer below has to absorb nonmetallic inclusions floating out of the liquid steel. Moreover, this layer has to shield the liquid steel against ingress of ambient air. However, the most important task of the slag layer is to provide the gap between stand and mould a with liquid flux film[2]) to keep both separated from each other. This flux film has to lubricate the strand withdrawn out of the mould. Beyond this, the flux film must safeguard a controlled heat transfer from the strand to the mould in accordance with the requirements of individual steel grades and casting conditions.

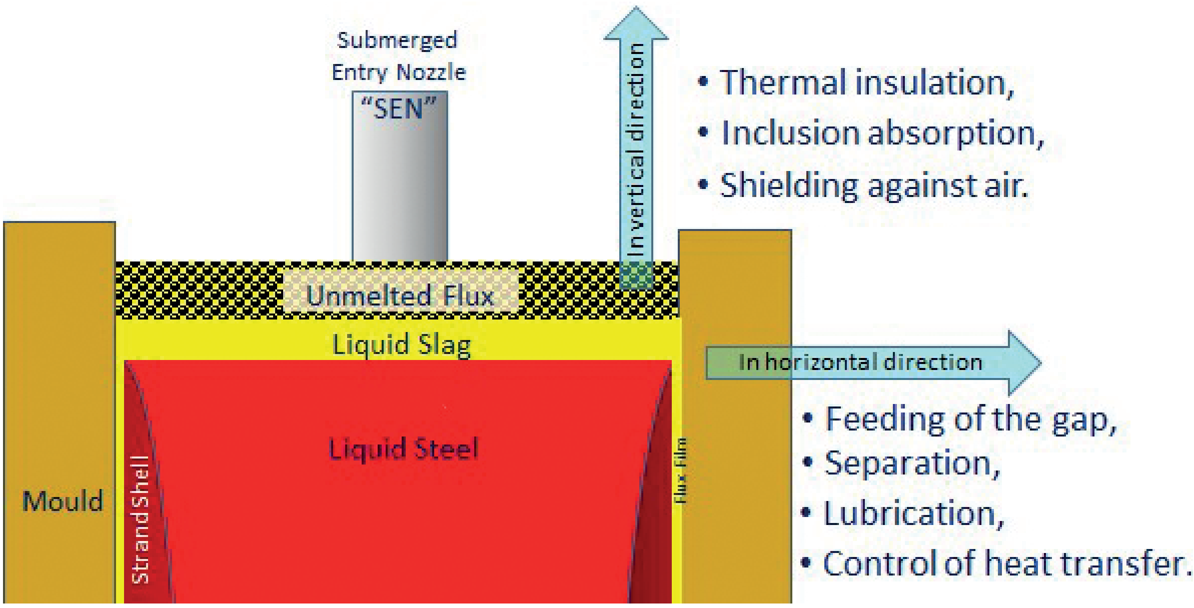

Fig. 1 - Functions of mould flux in vertical and horizontal direction.

Mould fluxes are blends of various minerals and carbon carriers. Mould fluxes can be characterized by their chemical analysis and physical properties like softening, melting and flowing temperature, melting speed, viscosity, break temperature etc. These characteristics are suitable for adjustment of technological properties.

TOOLS FOR ADJUSTMENT OF MOULD FLUXES

The thickness of the unmelted flux layer and its thermal insulating efficiency depend on the quantity of added powder and on its melting speed. The carbon carriers separate the various mineral

Dirk Eckhardt
Prosimet-Vostok

components from each other. As the mould flux comes into close contact with liquid steel, the carbon burns off. As the minerals get into direct touch, they start to melt. The amount and selection of appropriate carbon carriers are an essential influence on the combustion reaction and the melting speed of the mould flux. Reduced carbon contents in the blends and application of more reactive carbon carriers accelerate the melting process and decrease the thickness of the unmelted layer respectively.
The thickness of the liquid slag pool results from the melting rate of the unmelted top layer on the one hand and from the powder consumption on the other hand. The mould powder consumption depends on casting parameters like casting speed and oscillation[3]). It also depends on mould flux properties like slag viscosity. Faster melting rates can be balanced by application of lower viscous slags to keep the slag pool thickness constant. Several models are available for estimation of the slag viscosity based on its chemical composition[4,5,6]). This allows a controlled viscosity adjustment by powder slag analysis.
The heat extraction in mould depends on the chemical composition of the flux film, in particular on its basicity and fluorine content. Especially the basicity affects the break temperature[7]), which indicates the crystallinity of slags. Crystalline precipitations in the flux film reduce its heat conductivity. Furthermore, the heat extraction in mould also depends on the thickness and colour of the flux film.
In the following case studies, measures based on the above considerations serve to eliminate surface defects.

Case Study 1 - Corner Close Depressions in Combination with Narrow Face Bulging

Corner close depressions mainly occur in case of peritectic steel grades. Often they arise together with narrow face bulging and longitudinal cracks as schematically shown in Fig. 2.

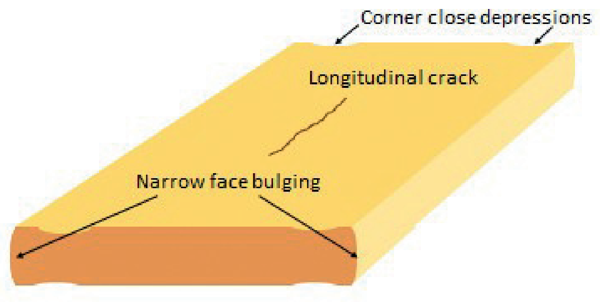

Fig. 2 - Corner close depressions combined with narrow face bulging and long cracks

Just after solidification, peritectic steels modify from ferrite to austenite. This is linked with a volume contraction and a shrinking of the strand shell box. In consequence, the contact between strand and narrow faces can be lost. Due to the missing support, the strand shell turns towards the narrow face resulting in narrow face bulging. Due to the two-dimensional heat extraction, the corners of the strand are quite stable in comparison to the plain surfaces.

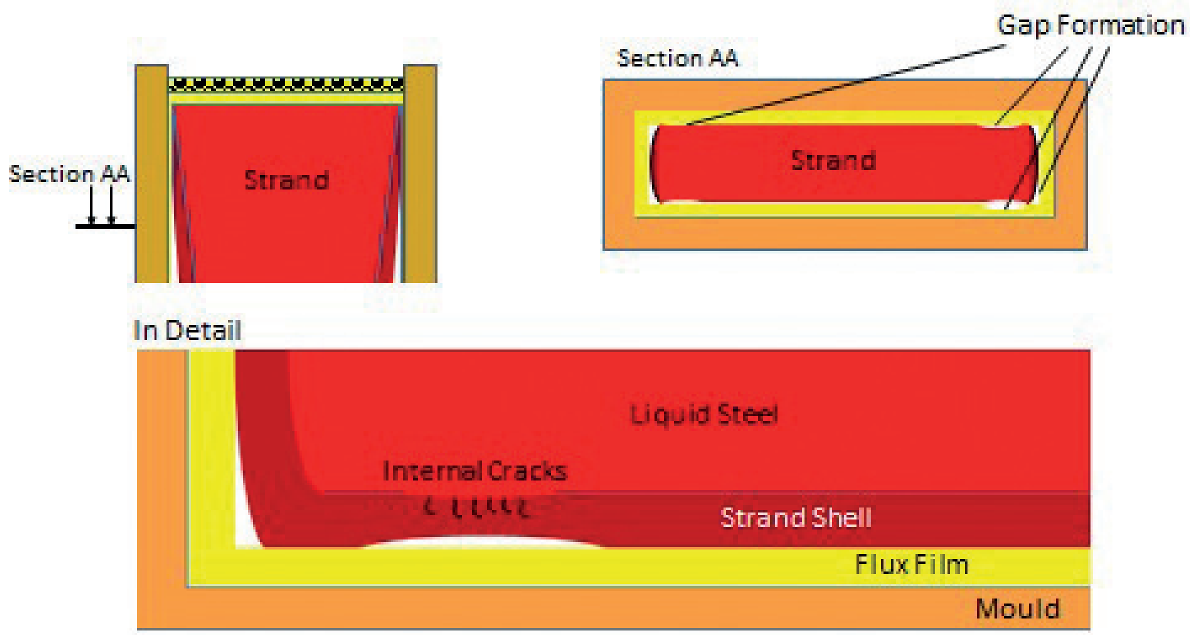

Fig. 3 - Mechanisms of narrow face bulging and formation of corner close depressions

As a result, the wide faces turn away from the mould forming a gap in the corner close area as narrow face bulging occurs. The gaps locally reduce heat transfer and solidification. The inhomogeneous strand shell thickness results in internal stress and inner cracks. Fig. 3 illustrates the mechanism of narrow face bulging and formation of corner close depressions.

Already when passing the mould, the strand surface of peritectic steels may modify to austenite in contrast to the subsurface areas. In this case, the density difference between the austenitic surface layer and the deeper, ferritic areas leads to material stress that effects longitudinal midface cracks, as illustrated in Fig. 2.

In order to moderate the shrinkage of the strand shell box, the heat extraction in mould must be reduced. A suitable way to diminish the heat transfer across the film is the reduction of its transparency by precipitation of solid particles in the liquid slags. Regarding mould flux chemistry, cuspidine is a suitable phase to cloud the flux film. Cuspidine is a calcium silicate mineral with the stoichiometry $3CaO*2SiO_2*CaF_2$. It is evident that mould fluxes precipitate the more cuspidine the closer their chemistry to that stoichiometry. For that reason, mould fluxes for peritectic steel casting have besides high fluorine contents high basicities (CaO/SiO_2) typically between 1.1 and 1.3. These basicity values lie below the CaO/SiO_2-ratio of cuspidine. As empirical formulas for the break temperature of slags indicate[7]), the increase of the basicity enhance crystallinity of slag. Thereby, it reduces thermal conductivity by precipitation of solid particles in the slag film. Thus, the increase of the basicity is a common measure for elimination of abovementioned defects, which are typical for peritectic steels.

Anyhow, the same defects could also result from an improper taper alignment of narrow faces. For that reason, the taper should be checked as above mentioned defects occur.

Case Study 2 - Corner Close Depressions on Slabs with Low Carbon Content

Corner close depressions sometimes occur on slabs even with low carbon content. Occasionally they arise together with corner cracks. These depressions happen especially in case of high casting speeds and small widths. As shown in Fig. 4, the mid-face thermo-diagrams indicate stable in-mould conditions under these casting conditions. In contrast, the corner close thermo-diagrams show a jumpy trend. Beyond this, the low temperature difference between both measurement levels indicate the risk of a sticker breakout. This points to the origin of the problem. As shown in Fig. 5 the flow pattern inside the solidifying strand shell box causes a strong wave formation in front of the narrow faces. The extent of wave formation increases with increasing casting speed and decreasing slab width. In extreme cases, there is no liquid slag on top of the wave anymore as illustrated in Fig. 5a. In consequence, the gap between stand and mould is not fed with liquid slag anymore and both can come in direct contact resulting in lack of lubrication. Due to the missing flux film the heat transfer becomes excessively high in the corner close areas of the wide faces. This effects the longitudinal depressions next to the corners.

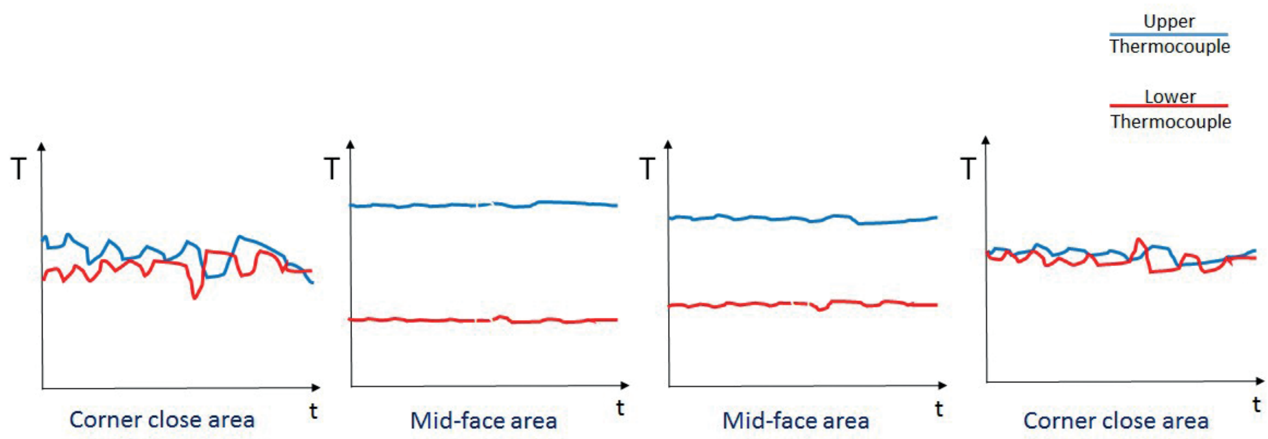

Fig. 4 - Temperatures thermocouples close to the corner and in the centre area

After replacement of the mould flux by a more viscous one, the temperature difference between both measurement levels of the breakout warning system increase spontaneously as shown in Fig. 6. A few minutes later a substantial temperature difference on constant level indicates stable casting conditions.

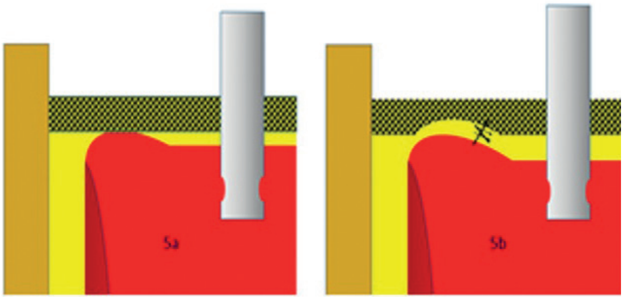

Fig. 5 - Liquid pool thickness by application of flux with low (5a) and with increased viscosity (5b).

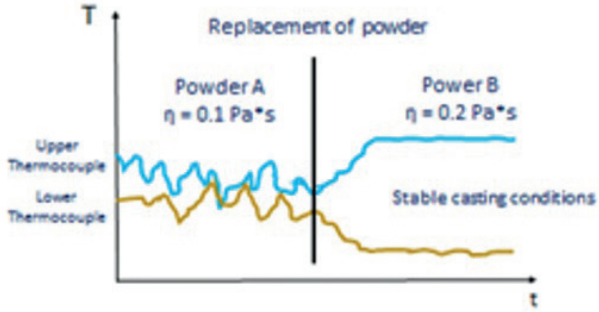

Fig. 6 - Thermo-diagrams in case of mould powder replacement by a more viscous one.

In many cases the application of a more viscous flux is a suitable measure to avoid longitudinal depressions caused by poor penetration of the gap in the corner close areas. It reduces the mould flux consumption and thus increases the slag pool thickness on top of the meniscus. Additionally, it delays the slag flowing down the wave as indicated in Fig 5b. Thus, the increase of the slag viscosity acts in a twofold manner.

Case Study 3 - Mould level fluctuations

Mould level fluctuations effect an inhomogeneous strand shell growths often causing longitudinal cracks [8,9]). At the worst, they result in breakouts. Mould level fluctuations typically occur in case of peritectic steel casting with high casting speed. Mostly they start after transient casting conditions like ladle exchange, flushing of the submerged entry nozzle (SEN) and removing of slag rims in mould. Fig. 7 exemplifies the origin of mould level

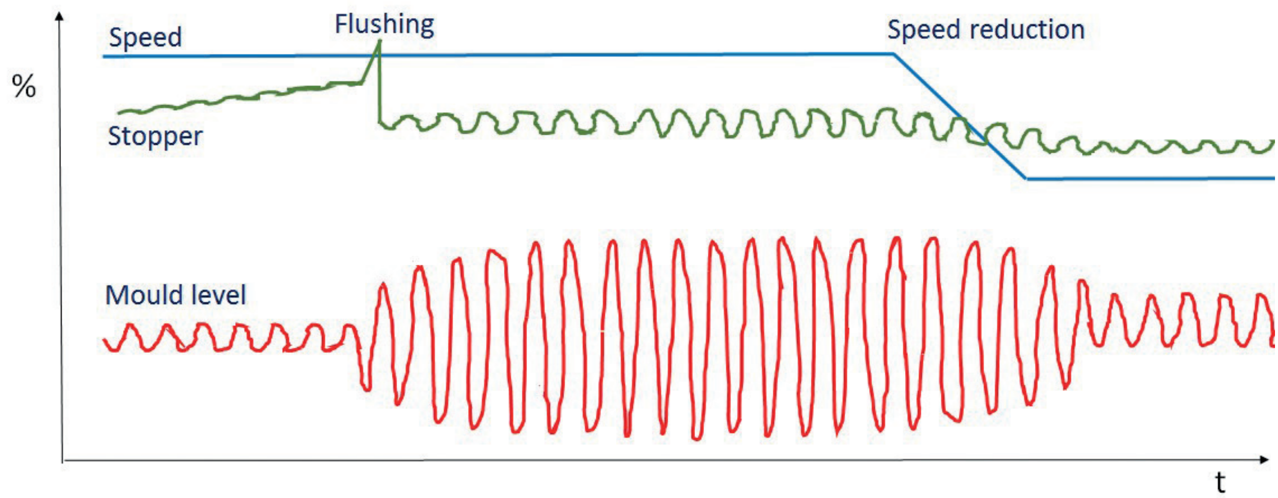

Fig. 7 - Stopper position, mould level and casting speed in case of fluctuation.

fluctuations. At constant casting speed, the rising stopper position indicates clogging of the SEN. Thereupon the operator lifts the stopper to flush out the accretion of alumina built-up. Immediately afterwards the mould level gets out of control. In order to reduce the amplitude of the fluctuations the operator lowers the casting speed.

By pumping or flushing, the meniscus first goes significantly up beyond the setpoint and afterwards below it. While going down the remaining slag traces freeze on the mould wall. This frozen layer does not melt anymore as the meniscus rises again. Thereby the flux film thickness between strand and mould grows and the heat extraction in mould goes down. In consequence, the solidification retards and the strand shell box just below the mould becomes weak. This results in bulging. The roller pairs in the segments below the mould squeeze the slabs whenever their thickenings pass them by. The periodically rising and falling mould level increases the thickness of the frozen slag film layer by layer. This reduces the heat extraction additionally resulting in an amplification of the fluctuations.

As already described, usually crystalline mould fluxes with high basicities are in application for casting of peritectic steels. The decrease of the break temperature of the slag by lowering of its basicity reduces the extent of freezing of the slag layer on the mould wall. Anyhow, a significant reduction of the slag crystallinity is impossible in case of peritectic steels. It would cause detrimental defects. For that reason, the potential of mould flux adjustment to avoid fluctuations is limited. Thus, mould flux adjustment is not a stand-alone solution in case of such complex problems like fluctuations. The implementation of additional countermeasures is required.

The improvement of the castability is an essential step to avoid unstable casting conditions like flushing of SEN to tear off alumina accretions, which often results in mould level deviations. The prevention of carryover of slag from furnace to ladle and from ladle to tundish is a crucial step towards clean steel.

Modifying ladle metallurgy may also help to improve cleanness and castability of steel. Usually argon rinsing of steel in order to reduce nonmetallic inclusions in steel is carried out after calcium treatment in ladle. Thereby the argon bubbles enrich in gaseous calcium on its way towards the bath surface. The loss of calcium in steel deteriorates the castability. Argon rinsing before calcium treatment diminishes the number of nonmetallic inclusions just before their morphology modification. This improves the castability and it reduces simultaneously the quantity of calcium required for modification of nonmetallic inclusions.

In other cases, an adjustment of caster settings is required in order to prevent fluctuations. The reduction of the primary mould cooling water flow rate to minimum practicable values might decrease the layer thickness of frozen slag sticking to the mould. This measure stabilizes the strand shell box and reduces its bulging. The increase of the secondary spray cooling just below the mould has the same effect. When limited to the upper cooling zone, there is no major impact on surface quality of crack sensitive steels to be expected. In addition, roller geometry has an essential effect. Equidistant rollers with identical diameters may amplify the mould level fluctuations.

CONCLUSION

The case studies presented above reveal that in particular the surface quality, but also the operational safety of continuous casting depend on the mould flux performance and properties. Many defects can be avoided by fine-tuning of mould fluxes. In complex cases, several approaches are required. Sometimes modification of caster settings or changes of secondary metallurgy are inevitable.

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