

IMPACT OF THE DENSITY OF THE MOULD POWDER ON THICKNESS OF THE LAYER OF LIQUID SLAG IN THE CONTINUOUS CASTER MOULD

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The paper presents results of measurements of the thickness of liquid slag layer in concast mould for pulverized, granulated or formed mould powder. The thickest layer of liquid slag was obtained for formed powders.

Key words: steel, slag, mould powder, continuous casting

INTRODUCTION

The demand of highest possible effectiveness is put on all production processes, while the highest quality is demanded from products. These requirements are particularly justified in the steel industry, due to high cost of technical equipment assembly and production cost. In such conditions continuous processes are of significant meaning, since they facilitate maximum utilization of production equipment capacity as well as mechanization, automation and computerization of the process. One of the processes that was subject to a particular development in the recent several dozens of years is continuous casting of steel.

Remarkable production and economic effects of continuous casting cause that this advanced material technology is still developing, which results in the change in the form of material used for process optimization and protection of the cast slab from formation of various defects.

Mould powders play a key role in continuous casting of steel, therefore the quality of slab depends mostly on the said powders. In view of that, all research on the desired properties of the applied powders become of significant meaning.

Effective mould powders should:

- protect liquid steel meniscus from oxidation,
- lubricate the cast strip,
- ensure the optimum horizontal exchange of heat for the cast steel grade,
- absorb non-metallic inclusions emerging from liquid steel [1].

Proper satisfaction of the said functions is possible with properly selected physical and chemical properties of powders, irrespective of the form these are supplied to the mould of the CCM.

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MECHANISMS OF SLAG INFLUENCE ON THE PROCESSES OCCURRING IN THE CONCAST MOULD

Mould powder should ensure stable operations of the continuous casting machine as well as manufacturing of high quality slabs without surface defects. Mould powder in a solid form (pulverized or granulated) introduced on the surface of steel (meniscus), melts affected by the temperature, thus forming liquid slag pool, as a result of which a laminar cover is formed.

Mould powder covers the surface of liquid steel, thus forming the layer of liquid slag being in direct contact with metal, the intermediary phase composed of semi-liquid and sintered phase as well as loose layer of pulverized or granulated mould powder which remains in contact with atmosphere.

Physico-chemical properties of the said cover change continuously from metal surface to the surface in contact with atmosphere and separation of three, or in some cases higher number of layers is just a matter of convention. Formation of the said cover of stable properties during casting process requires adjusting the rate of powder feeding to melting rate on steel surface and stable parameters of casting (nozzle submersion, casting rate, proper modification of CaSi steel, i.e. no clogging of nozzles, etc.).

During melting of slagforming materials of the powder, simultaneously the process of infusible component burning occurs (carbon or boron nitride) and melted layer flows out on the surface (unburnt excess).

Melted powder in form of mould slag changes its physicochemical properties on steel surface as a result of evaporation of volatile components (alkaline oxides, fluorides), assimilation of non-metallic inclusions and chemical compounds adsorbed on steel surface, as well as melting of ceramic material of submerged nozzles in mould slag. The feature of mould slag consisting in stability of its physicochemical properties in spite of variable chemical composition (in particular increase in

aluminium oxide content) is its capacity. This is a qualitative feature of mould slag. Low capacity slag (mainly in reference to Al_2O_3) clearly changes its properties during continuous casting process.

Liquid slag flows into the gap formed between the solidifying meniscus layer of steel and mould walls. Its refining properties are particularly important in the area of meniscus layer, the shape of which alters as a result of unbending (getting out the slab from the mould) and as a result of mechanical interactions with oscillating mould (formation of oscillation marks and hooks). In the case when too large volumes of adsorbed oxide or sulfide bindings occur in the solidifying meniscus layer, it becomes brittle and cracks as well as liquid metal spills are probable, which leads to formation of surface defects on the cast slab.

Refining properties of mould slag allowing to maintain maximum purity of meniscus layer depend mainly on surface properties of slag in interphase boundaries with liquid steel and possible non-metallic inclusions flowing out of liquid steel. Mould slag flowing in the gap between solidifying slab and mould wall solidifies in contact with a cold wall of the mould, covering it with side ledge (glassy film). The shape of side ledge in the area of meniscus layer changes cyclically in line with oscillation movements of the mould. It depends on the viscosity of the mould slag flowing in the gap and parameters characterizing its solidification (mostly slag solidification temperature), and parameters of mould oscillation as well as the manner of heat transfer in this area of mould. There are at least two layers of solidified and liquid slag between mould wall solidified surface of slab. Depending on the cooling rate (temperature of slab surface at the end of the mould) the layer of slag covering the slab coming out of the mould, is either in liquid or solid state. The volume of mould slag getting out of the mould, depends on the powder melting rate, width of the gap formed between the slab and mould (contraction of the cast steel during solidification), viscosity of mould slag and the nature of mould oscillation (stroke size oscillation frequency). The velocity of slag flow between the slab and mould should guarantee filling in the totality of the said space, as formation of the matter of heterogeneous physicochemical properties (of discontinuous changes in physico-chemical properties, e.g. gaps filled with gas) is a reason for occurrence of thermal stresses, the consequence of which are surface defects of slab.

During stable casting, powder feeding rate, powder melting rate and the velocity of slag flow in the space between slab and the mould as well as the velocity of slag outflow from the mould should reach the level ensuring stationary (mould oscillation not taken into account) flow of powder in various forms starting from the moment of introduction to the mould of loose, pulverized powder, till slag outflow from the mould [2].

INDUSTRIAL TESTS

Research material for determining the thickness of liquid layer of mould slag was pulverized, granulated

and formed powder (plates). Samples prepared on the basis of Scorialit SL 470/M powder (pulverized) and ALSIFLUX GS-C7.3 powder (granulated) used for slab casting were subject to tests. Binding agent was added to pulverized powder in order to form homogenous plates. Following drying, powder mould was obtained in form of plates with shapes adjusted to the mould intersection (Figure 1). Analysis of chemical composition of the powders was executed at the Chemical Analyses Laboratory of the Institute for Ferrous Metallurgy while its results are presented in Table 1.

Measurement of the depth of liquid mould slag was effected by simultaneous introduction of copper and steel wires to the mould. Following introduction to the mould, steel wire melts in liquid steel, while copper wire melts in mould slag. Difference in length between wires indicates the depth of the liquid phase of slag. The achieved results along with selected parameters of casting for particular types of mould powders are presented in Table 2 Tests were conducted during casting of low carbon steel slabs in one of the Polish steel plants. Two industrial tests were conducted for powder in form of



Figure 1 Plates of formed mould prepared by means of manual compacting during industrial tests of powder application in concast mould

Table 1 Chemical composition of mould powders used during tests / wt %

Component	Mould powder		
	Pulverized	Granulated	Formed
Al_2O_3	4,44	5,11	4,56
C_{free}	5,96	6,41	8,31
F	7,88	7,63	8,62
CaO	29,76	29,65	26,50
Fe_2O_3	0,95	1,74	0,93
K_2O	0,44	0,40	0,48
Li_2O	< 0,002	< 0,002	< 0,002
MgO	1,51	1,19	1,52
MnO	0,09	0,05	0,06
Na_2O	8,35	8,47	8,85
SiO_2	32,21	29,90	31,66
TiO_2	0,21	0,24	0,21
CO_3^{2-}	12,90	11,90	11,90
CaO/ SiO_2	0,92	0,99	0,84

Table 2 Depth of liquid phase of mould slag and selected parameters of casting during industrial tests

Form of powder	Depth of liquid phase of powder / mm	Casting rate / $\text{m}\cdot\text{min}^{-1}$	Casting temperature / K	Frequency of oscillation / min^{-1}	Powder viscosity* / $\text{dPa}\cdot\text{s}$
Granulated	24	1,1	1816	97	0,47
Formed	A	1,1	1814	97	0,34
	B	1,1	1811	97	
Pulverized	25	1,1	1817	97	0,45

*calculated as per Riboud's formula [3 - 5]

formed plates and one test for pulverized and granulated powder for the purpose of comparison.

Deeper liquid phase of mould slag obtained under formed powders ensures more stable heat flow on the circumference of the mould and results in achieving improved lubrication of mould walls as well as concast slab skin.

Impact of mould powder on the surface of concast slab is related to formation of liquid slag pool on the surface of metal in the mould (meniscus), which fills in the gap between the skin and the mould during mould forward slip t_{neg} . It is important that proper depth d_p of the liquid slag pool is ensured, to guarantee constant and uniform lubrication on the entire circumference of slab.

A parameter controlling the manner of mould lubrication is the volume of mould powder consumption, related to thickness of the so called liquid film, and depth of oscillation marks. This also depends on viscosity of powder and casting rate (increase in these parameters' level results in consumption reduction), frequency of mould oscillation and time of forward slip (reduction in these parameters' level results in increase in powder consumption - Q_t).

Unit consumption of powder, Q_t was expressed in kg/Mg (Table 3) due to obtaining exact data on consumption of particular forms of powder, and reference thereof to the length of the cast strip.

Balances of exploitation materials developed in the steel plant imply that the average consumption of granulated powders is $0,6 \text{ kg}/\text{Mg}$.

Lower consumption of formed powder ($Q_t = 0,56 \text{ kg}/\text{Mg}$) as compared to granulated ($Q_t = 0,6 \text{ kg}/\text{Mg}$) and pul-

Table 3 Unit consumption of mould powder during industrial experiments

Form of the powder	Length of the strip cast under powder / m	Mass of steel cast under the powder / Mg	Mass of the delivered powder / kg	Powder consumption / kg/Mg
Formed	A	6,42	11,45	6,50
	B	6,58	11,72	6,60
Pulverized	7,20	12,82	10,0	0,78

verized powder ($Q_t = 0,78 \text{ kg}/\text{Mg}$) at deeper liquid phase of mould slag, indicates that application of formed mould powders allows to improve lubricating conditions and simultaneously to obtain positive economic effect.

SUMMARY

The role of mould powder is to provide thermal and chemical protection of liquid steel surface during last stage of its production which is (CCM) continuous casting. The efficiency of insulating layer depends, inter alia on thickness of the formed solid layer of powder and liquid mould slag.

Based on the conducted industrial tests, it was ascertained that:

- casting under all forms of mould powder: pulverized, granulated and formed was effected without any disruptions, at similar values of casting parameters,
- addition of binding agent to the production of formed mould has slightly reduced its viscosity as compared to the base (pulverized) mould powder, however it did not change both mineralogical and chemical composition,
- the largest depth of liquid phase of slag (27 - 30 mm) was recorded for powder of the highest density, i.e. for formed powder,
- change in density of mould powder may affect the conditions of vertical heat flow in the mould as well as depth of slag pool,
- measurements of temperature recorded on thermocouples installed in mould walls have not recorded differences in horizontal heat flow,
- the lowest unit consumption of mould powder ($0,56 - 0,57 \text{ kg}/\text{Mg}$) was recorded for the formed mould powder,
- qualitative analysis of slabs cast with application of all the tested powders has not show significant differences in the quality of concast slabs,
- no differences were observed in the quality of sheets rolled from slabs cast under various forms of mould powder.

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