DESIGN AND INDUSTRIAL VERIFICATION OF THE CHEMICAL COMPOSITION OF MOULD POWDERS FOR CASTING PROCESS OF C45 STEEL

KANIA Harald[1], LIS Teresa[1], NOWACKI Krzysztof[1], SATERNUS Mariola[1]

[1]*Silesian University of Technology, Faculty of Materials Engineering and Metallurgy, Katowice, Poland, EU*
harald.kania@polsl.pl

Abstract

Mould powders significantly influence the correct course of steel continuous casting process, the surface quality and subsurface structure of round billets. For many users of continuous casting equipment the choice of proper mould powder for the local condition of casting process is still the essential problem. The solution of such problem could be empirical equations (worked out in the last years), which with more and more accuracy enable to determine the values of physicochemical parameters of mould powders for the parameters of casting process of specific steel grade. The article presents the way of using the empiric equations to determine the physicochemical properties of mould powders dedicated for casting the round billets (Ø 170 mm) from C45 steel and their verification in industry.

Keywords: Mould powder, casting process, physicochemical properties

1. INTRODUCTION

Slag creating oxides (SiO_2-CaO with addition of Al_2O_3) are the basic elements of mould powder mixture (70 % of the total powder). Small amounts of MgO can be replaced by CaO or alkaline oxides. Oxides of alkali earth and fluorine (MnO, Na_2O, K_2O, Li_2O, Fe_2O_3, FeO, CaF_2, MgF_2, NaF, LiF) belong to the group of liquefying additives (decreasing the melting temperature and viscosity). If the high alloy steel is casted, to the chemical composition of mould powder is added also TiO_2 and ZrO_2. The regulator of mould powder rate is coal in free form (e.g. graphite, soot, ground coke). The chemical composition of mould powders is designed basing on the mineral components; while mineralogical composition is very often secret of manufacturers.

Because of the direct contact of the mould powder with the surface of liquid steel in mould it influences the changes of the steel surface properties and play the role of lubricants. Mould powders are introduced from the top to the mould on the liquid steel surface. Liquid slag as a result of powder melting is moving down among the mould creating between the billet surface and mould the slag film composing with some liquid crystalline and glassy layers [1]. Therefore, heat transfer through the slag film is strongly dependant on the thickness and heat conductivity of each layer. Thickness of slag film in solid state increases with the increase of viscosity and decrease of heat transfer quantity. Physicochemical properties of the steel and mould powder as well as casting parameters influence the heat transfer between the billet and mould. In the industrial practice the calculation of heat transfer can be determined basing on the balance of taken heat by the water cooling the walls of the mould. The total heat transfer from liquid billet core to the mould can be estimated as a function of temperature of cooling water using the following equation:

$$\Phi = c_p \cdot p \cdot \Delta T_m \qquad (1)$$

where:

Φ - *heat transfer between the strand and the mould*, *kJ / min,*

ΔT_m - temperature difference between water incoming and outcoming from the mould, *°C,*

c_p - *specific heat of water*, *kJ / kg / °C,*

p - water flow in mould, *kg / min.*

Values of Φ and ΔT can be the factors informing about lubrication intensity of billet skin, thus about the suitability of the applied mould powder. The optimum of lubrication can be achieved regulating appropriately with the technological parameters and physicochemical properties of the mould powder. The liquid slag solidifies in different temperature depending on the basicity and chemical composition of mould powder. The higher is basicity, the higher is temperature of mould slag solidification. The stability of slag coating can be kept only if the liquid slag is constantly delivered to the area of mould and billet, what is controlled mainly by the depth of liquid slag layer d_p on the liquid steel surface [2]. Casting conditions, applied mould powder and the format of the mould could influence the depth of liquid slag layer, and it can be 15 - 30 mm for slabs or 6 - 12 mm for billets [3]. Thus, the measurements of d_p is one of the factors used to estimate the lubrication intensity of billet skin Q_s. The change of liquid slag depth and its viscosity can be caused also by changes of friction forces F_r in mould calculated according the following equation:

$$F_r = \frac{\eta_s \cdot v_r \cdot s_A}{d_p} \tag{2}$$

where:

η_s - slag viscosity, Puaz,

v_r - relative velocity of mould movement accorrding the billet, m/min,

d_p - depth of liquid phase of mould slag, mm,

s_A - area of mould and billet contact, m^{-1}.

Friction, which occurs in the lower half-mould between two solid bodies, can lead to flaky slag film, creating air emptiness, possibilities of sticking the mould walls to the billet surface; and as a consequence defects creation in the billet surface is observed. **Figure 1** shows example of billet surface defects caused by excessive friction in mould during casting process of C45 steel (**Table 1** shows the chemical composition of this steel).

Figure 1 Surface defects of Ø 170 mm billet cast from C45 steel

Table 1 Chemical composition of C45 steel, % mas

	C	Mn	Si	S	P	S	Cr	Ni	Mo	Al
Min.	0.42	0.50	0	0	0	0	0	0	0	0.020
Max.	0.50	0.80	0.40	0.045	0.045	0.045	0.40	0.40	0.10	0.050

High difference between temperatures of water out-coming to incoming to the mould (ΔT = 8 ÷ 10 °C) is the first indication that there is possibility to occur high friction in mould, which is responsible for creating deep and non-uniform distributed on the billet circuit oscillation marks. The excessive friction can be caused by different factors (mechanical causes with excessive consumption of mould oscillation units, misplaced guide rolls, introduction of starting bar, by application of improper value of oscillation parameters such as stroke, cpm or mould powder).

2. DESIGN OF CHEMICAL COMPOSITION OF MOULD POWDER

To correct the applied technology it was decided to determine the optimal physicochemical parameters of mould powder to the used parameters of casting process of round billets Ø170 mm. For the design of mould powder chemical composition the calculation method described in [4] was used. Ferrite potential calculated according equation (3) and (4) for steel C45 equals 0.12 (steel type B). Then basing on the condition shown in **Table 2** it was determined the values of physicochemical properties of mould powder for casting C45 steel (see **Table 3**).

$$FP_C = 2.5 \cdot (0.5 - [\%C]_r) \quad (3)$$

where:

$$[\%C]_r = [\%C] + 0.02\,[\%Mn] - 0.037\,[\%Si] + 0.023\,[\%Ni] - 0.7\,[\%S] + 0.0414\,[\%P] + 0.003\,[\%Cu] - 0.0254\,[\%Cr] - 0.0276\,[\%Ti] + 0.7\,[\%N] \quad (4)$$

Table 2 Physical parameters of mould powder as a function of ferrite potential

Physical parameters of mould powder	Steel groups		
	FP_C = 0.85 - 1.05 Steels type A *PERITECTIC*	FP_C < 0.50 Steels type B *STICKER*	FP_C = 0.51- 0.84 and FP_C > 1.06 Steels type C *OTHERS*
Dynamic slag viscosity; η (Puaz)	high	low	average
Basicity; CaO / SiO_2	high	low	low
The melting temperature, T_{liq} (°C)	high	low	average
Break temp. / viscosity, T_{br} / η (°C)	high	low	average
Mould powder conductivity, $k_{sys.(1200°C)}$	low	high	high / average
Slag crystallinity, NBO/T	> 2	< 2	≤ 2

3. INDUSTRIAL EXERIMENTS

Round billets Ø 170 mm (C45 steel) are cast in continuous casting (CC) machine (three strands) with arc radius R = 6 m. There are installed two electromagnetic stirrers (M-EMS and F-EMS type). C45 steel is cast under the mould powder Scorialit SPH C 189/E1 in the full protection of flux through submerged pouring nozzles to the Convex type moulds. To increase the quality of round billets firstly the inspection of CC machine mechanism and its regulation was done, then casting tests were carried out using new mould powder. Because mould powder with the chemical composition described in **Table 4** was not present in the steelwork; so powder with the nearest physicochemical properties was chosen to industrial tests. It was granular powder Scorialit SPH 176/ALS 9 produced by Metallurgica (its characteristics shows **Table 5**).

Experiments and industrial measurements were conducted on two strands no 2 and no 3. In casting process on strand no 2 powder Scorialit SPH C 189/E1 was used; while on strand no 3 new powder Scorialit SPH 176/ALS 9. **Table 5** presents the average values of casting parameters and measurements of liquid slag depth. Basing on equation (1) and (2) the heat flux from liquid steel to the mould and values of friction forces were calculated.

Table 3 Physicochemical properties of mould powder for casting round billets Ø 170 mm from C45 steel

Physical parameters	Dynamic slag viscosity at 1300 °C, η_{1300}	6.3 Puaz
	Slag crystallinity, *NBO/T*	1.47
	% of crystallinity, *%*	-76.2 %
	Mould powder conductivity, $k_{sys(1200°C)}$	1.75 W / mK
Chemical analysis, %mas.	SiO_2	~ 30.0 % mas.
	CaO + MgO	~ 28.0 % mas.
	Al_2O_3	~ 7.5 % mas.
	$Na_2O + K_2O$	~ 7.0 % mas.
	MnO	~ 2.0 % mas.
	Li_2O	~ 2.0 % mas.
	CaF_2	~ 7.0 % mas.
	C_{free}	~ 23.5 % mas.
	Basicity: CaO / SiO_2	0.9

Change of powders from Scorialit SPH-C-189/E1 to Scorialit SPH-C-176/AIS9 caused the change of heat condition in mould and lubrication of round billet surface. Preserving the same casting parameters on the both strands (no 2 and no 3) it was obtained the biggest depth of liquid flux pool from 3 - 4 mm to 12 - 13 mm to Scorialit SPH-C-176/AIS9 advantage. Thank to that the better lubrication condition was obtained and also the better heat offtake to the mould walls; as a result there was two degree difference in temperature increase of water cooling the mould (ΔT) between two strands. Better lubrication of mould walls decreased over three times friction in mould. Visual observation of the strand surface coming out from the secondary cooling chamber and billets moving on the runout tables indicated difference in the amount of solidified mould slag stuck to billets surface - see **Figures 2a** and **2b**.

Two times higher percentage of slag crystallity of Scorialit SPH-C-176/AIS9 powder comparing with Scorialit SPH-C-189/E1 powder caused the decrease of heat flow flux from billet to mould (about 17348.41 kJ / min). On the analyzed strands measurements of thermovision camera revealed the temperature difference on the cast billets surface. Temperature of the billet surface in the strand no 3 under tested mould powder was higher about 10 °C. The temperature difference of billet surface in strand no 2 and 3 can be reflected in the size and structure of dendrites. In strand no 2 and 3 in billets are observed equiaxed dendrites in the range of former austenite grains. In billet cast under Scorialit SPH-C-189/E1 main dendrites and their arms are overgrinding comparing with billet cast under Scorialit SPH-C-176/AIS9 (see **Figures 2e, f**). The results of topography measurements of billets surface (**Figures 2c, d**) cast under Scorialit SPH-C-176/AIS9 indicated that the depth of oscillation marks decreased about 20 %.

4. CONCLUSIONS

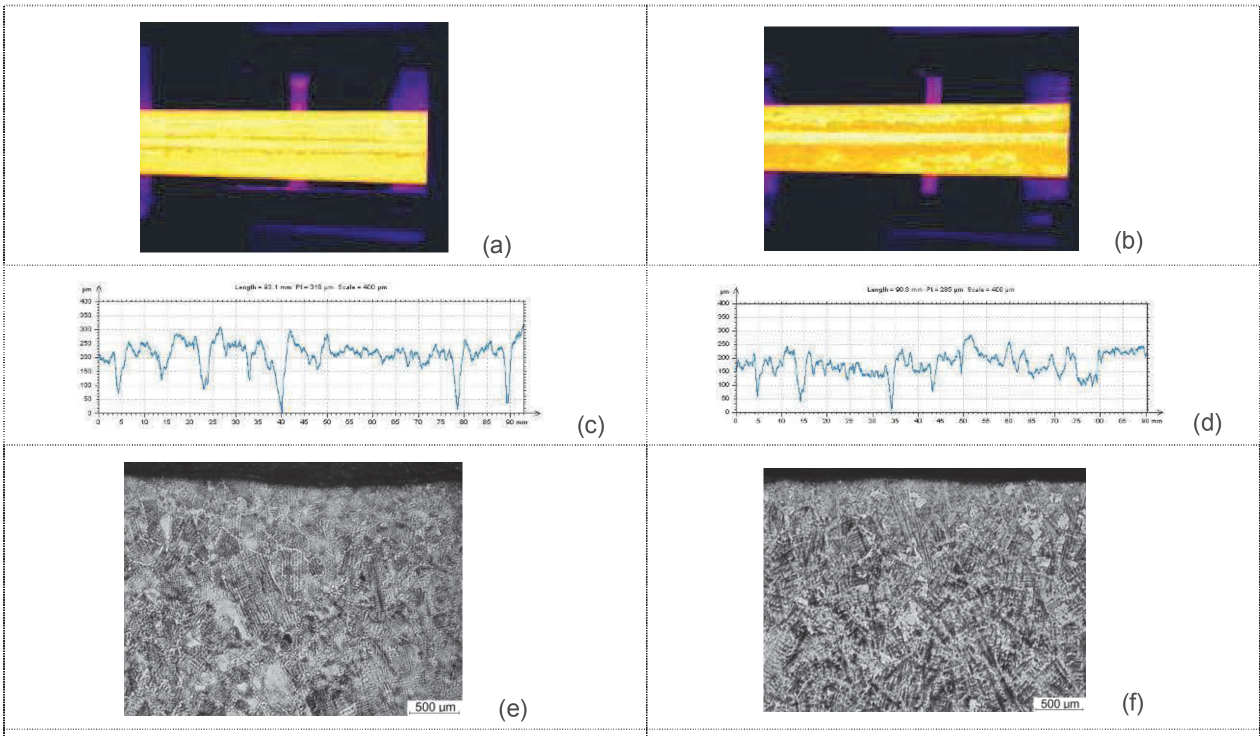
Casting under new mould powder Scorialit SPH-C-176/AIS9 undoubtedly improved the lubrication of mould walls and the quality of round billets surface. The differences, which were obtained between cast billets on two strands, were seen mainly in the size of dendrites. In billet cast under Scorialit SPH-C-189/E1 powder main dendrites and their arms are overgrinding comparing with billet cast under Scorialit SPH-C-176/AIS9; however that may mean that even though the tested mould powder Scorialit SPH-C-176/AIS9 obtain very good quality of billet surface and more favorably condition of lubrication in mould, it still creates the excessive amount of mould slag. Excessive creation of slag in mould and then its deposition on the strand surface works as isolator blocking the heat transfer to mould walls, in the same time causing the increase of steel temperature and growth of dendrites.

Table 4 Physicochemical properties of mould powder from Metallurgica plant

Type	Type of mould powder **Scorialit (Sc)**	**SPH-C 189/E1**	**SPH-C 176/ALS 9**	Unit
Chemical analysis	SiO_2	31.0 ÷ 33.0	27.5 ÷ 29.5	% mas.
	CaO + MgO	19.5 ÷ 21.5	30.0 ÷ 32.0	% mas.
	Al_2O_3	4.5 ÷ 6.0	5.0 ÷ 6.5	% mas.
	$Na_2O + K_2O$	10.0 ÷ 12.0	2.0 ÷ 3.5	% mas.
	Fe_2O_3	1.0 ÷ 2.5	2.0 ÷ 3.0	% mas.
	MnO	< 0.1	2.5 ÷ 4.0	% mas.
	C_{free}	18.0 ÷ 20.5	16.0 ÷ 18.0	% mas.
	CO_2	5.5 ÷ 6.5	5.5 ÷ 6.5	% mas.
	C_{total}	20.0 ÷ 22.0	17.5 ÷ 19.5	% mas.
	F	4.0 ÷ 5.0	1.0 ÷ 2.0	% mas.
	$H_2O_{600\ ^oC}$	< 0.8	< 1.0	% mas.
Basicity	CaO / SiO_2	0.53 ÷ 0.65	0.99 ÷ 1.11	-
Physical parameters	Bulk density, ρ_m	0.50 ÷ 0.70	0.70 ÷ 0.90	Kg /dm^3
	Melting point, T_{soft}	1000 ± 30	1070 ± 30	°C
	Fluidity point, T_{fluid}	1080 ± 20	1140 ± 20	°C
	Viscosity, η_{1300}	5.6	7.2	Puaz
	1) slag crystallinity, NBO/T	1.84	1.65	-
	1) percent of crystallinity, %	-24.2	-51.4	%
	2) Mould powder conductivity, $k_{sys(1200°C)}$	1.85	1.72	W / mK
1), 2) physical properties calculated according equations described in [5,6]				

Table 5 Casting parameters, results of calcualtions and measurements done during industraial experiments

Type of mould powder	Water flow in mould	Speed of casting	Average temp. of water	Mould oscillation			ΔT	Depth of liquid slag	Friction force	Heat flux
	P	v_C	T_{avg}	*s*	*cpm*	f_{osc}		d_p	F_r	Φ
Sc 189/E1	1657 l / min	1.91 m / min	24 °C	5 mm	105	199 c / min	9.1 °C	2-3 mm	7.5 kN	62947.64 kJ / min
Sc 176/ALS9	1655 l / min	1.91 m / min	24 °C	5 mm	105	199 c / min	6.6 °C	13-14 mm	2.2 kN	45599.23 kJ / min
where: specific heat of water - 4.19 kJ / kg / °C; water density in temperature 24 °C - 997.04 kg / m^3										



Strand no 2 (Scorialit SPH-C 189/E1)	Strand no 3 (Scorialit SPH-C 176/ALS 9)

Figure 2 Exemplary thermograms of cast strand surface a) and b) after coming from the secondary cooling chamber, topography of surface (c) and (d) and subsurface microstructure (e) and (f) of Ø 177 mm billet

The conducted tests with new type of mould powder indicated that the significant improvement of surface quality and lubrication of mould walls was observed; however the metallographic research of subsurface area of billets showed that it should be carried out additional research of C45 steel casting process under mould powder with physicochemical properties more similar to the designed mould powder.

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