DESIGNING THE PHYSICO-CHEMICAL PROPERTIES OF THE PRODUCT BASED ON TECHNICAL AND TECHNOLOGICAL PARAMETERS OF THE CUSTOMER PRODUCTION LINE

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Abstract

Designing the physicochemical properties of consumables used in the steel industry must be adapted to the technical and technological parameters of production equipment. Proper design of the properties of the consumables used in the production line allows for high-quality final product.

The article describes the use of a model for the design of the physicochemical properties of mould powders that meets the requirements of the local conditions of technological equipment CC based on the developed in recent years empirical rule. The model determines the physicochemical properties of the mould powder based on established procedures and consecutive logical steps, which include solving issues such as the proper classification of cast steel to a group of species, optimizing the parameters of the oscillation and lubrication conditions for the selected cross-section of the mould and to determine the optimal values of the three physical parameters of slag mould: basicity, viscosity, and crystallization temperature (breakthrough). The final composition of the backfill is fixed as a result of multiple calculations the aforementioned. Physical quantities, until the results of the most similar to the values assumed. Preliminary calculations indicate that the model correctly determines the chemical composition of the backfill for carbon steel and low-alloy cast at standard speeds in slabs.

Keywords: Steel, continuous casting, mould powder

1. INTRODUCTION

Mould powder have a significant effect on the correct course of continuous casting and the surface quality of billets. Despite the growth of expertise in the field of manufacturers of powders required physicochemical parameters, continued for many users the right choice of mould powder to local technical and technological casting is an important issue.

In most of the steelworks mould powders selection is based on the indication of the manufacturer, usually based on past experience with other devices CC, without taking into account local conditions of casting. Another way of selecting powders for a particular grade of steel is done by trial and error. Attempts to rely on running simultaneously casting the different species of backfill and choose the best based on visual observation, analysis parameters of the primary cooling, the liquid slag phase measurements and evaluation of quality of continuously cast. Accepted methods are burdened with always some degree of risk of failure and poor quality of billets CC. Also, the growing ecological requirements make it necessary to look for new ways to reduce harmful substances in supplies [1]. For this purpose is conducted in many research centers and industrial intensive research on understanding the mechanisms of lubrication, friction, heat flow in the mould etc. The works are, inter alia, to develop theoretical methods and procedures of selection of the chemical composition and physical properties of the backfill crystallizers, taking into account the assumed casting parameters and environmental standards.

Developed in recent years empirical formulas for the continuous casting of steel it possible not only to optimize the technological parameters of the casting, but may also be used to determine optimal values of the physical of slag (basicity, viscosity, break temperature) under which it is possible to design chemical composition of the mould powder.

2. ASSUMPTIONS ADOPTED FOR DESIGNING MOULD POWDER

Physicochemical properties of mould powder and technological parameters CC for a particular grade of steel, affect the way of surface lubrication skin of the billet formed in the mould and the head flux on the circumference of the billet. Mould powders are introduced into the mould from the top surface of the liquid steel, and gradually move down to the mould. The molten flux formed by melting mould powder forms on the surface of the liquid metal liquid flux pool supply space between the mould and strand of cast steel (air gap) and lubricates the newly formed solidified shell - **Figure 1** [2].

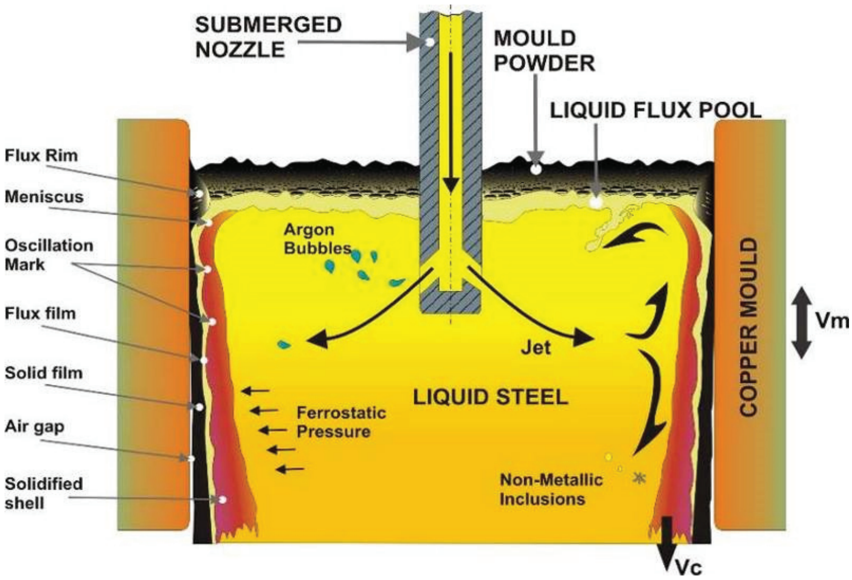

Figure 1 Slag layers formed during solidification of the steel in the mould [2]

The effectiveness of mould powder has a decisive influence on the surface quality of cast products in the CC process. Therefore, the effective interaction of mould powder on the processes taking place in the mould should ensure:

- wall lubrication of mould, to reduce friction force of solidification skin steel during bloom,
- protection of the metal surface in the mould before peroxidation and intruding,
- thermal insulation mirror of metal in the mould,
- assimilation of non-metallic inclusions and formed on the steel surface of the oxide type compounds, sulfide, etc.,
- impact on the size of the solidifying billet stress by providing an even flow of heat from the billet to the mould.

In recent years has developed several empirical equations to calculate physicochemical parameters to ensure the proper functioning of mould powder, mould fluxes slag and horizontal heat flow in the mould.

Using the developed empirical equations, you can select or design a suitable chemical composition of the mould powder for cast steel, grade cross-section of the billet and technological parameters used for a particular device CC.

Designing the chemical composition of the mould powder based on a model based on empirical equations will carry out in several steps:

- qualification of steel grade to the appropriate group of steel,
- determine the optimal parameters for the oscillation of the mould for cast billet section,
- determine the best lubrication conditions for billet,
- classification of billet/bloom/slab - setting the parameter R,
- determination of the values of selected physical parameters of powder,
- based on the above points - determination of the chemical composition of the mould powder.

Step 1 - Classification of grades of steel on the basis of the calculation of the potential of ferritic FP

Ferritic potential is one of the most important factors by which technological parameters as casting of steel in CC are determined. It is also used to determine the simplified distribution of steel group species. In work [3] based on the analysis of defects of continuously cast depending on the ratio of the phase components and the influence of the alloying elements are defined as ‚"Ferrite Potential", carbon steel and low alloy steels is:

$FP_C = 2.5 \bullet (0.5 - [\%C]_r)$ (1)

At Voestalpine [4] on the basis of their refined model for the carbon equivalence Wolf [5] the following form:

$[\%C]_r = C\ \% + 0.02 \bullet Mn\ \% - 0.037 \bullet Si\ \% + 0.023 \bullet Ni\ \% - 0.7 \bullet S\ \% + 0.0414 \bullet P\ \% + 0.003 \bullet Cu\ \% - 0.0254 \bullet Cr\ \% - 0.0276 \bullet Ti\ \%] + 0.7 \bullet N\ \%$ [5] (2)

where:

the FP values classify carbon steel and low-alloy into three groups [5]

FP = 0.85 - 1.05	**steel type A** - PERITECTIC, with tendency of depression grade in the mould; *this depends on steel composition and its tendency to either nonuniform shell growth*
FP < 0.50	**steel type B** - STICKER GRADE; with tendency of shell tearing and sticking to the walls of the mould [5]
FP > 1.06 and FP = 0.51 - 0.84	**steel type C** - OTHERS; other steels with a low tendency to "swell" - sticking to the walls of the mould

Depending on the classification of the steel for the group values are determined:

- technological parameters casting of steel in CC, ie. primary cooling (cooling intensity) - mould water flow rate,
- physicochemical properties of mould powder (see **Table 1**) and
- design parameters of the mould (for example mould taper).

Step 2 - Determination of the optimal oscillation parameters of the mould for continuous casting billet section

The oscillating movement of the mould and the changes that result in the formation of a meniscus of steel, directly affect processes: solidification of the steel, the flow of liquid slag and slag pressure changes in the air gap, and hence the lubrication of the billet and regulation of the heat flow.

Analysis of the oscillating movement of the mould includes a number of parameters of this movement, and additional relationships occurring between the main parameters. The main parameters are:

- casting speed v_C
- mould stroke s
- oscillating coefficient K_{osc}
- oscillation frequency f_{osc}

Other important parameters, such as time-step advance t_N and time-step reverse t_P are dependent only on the four independent parameters and the same defined.

To achieve proper lubrication conditions and heat flow in the mould, obtain the oscillation parameters closest to the value of:

- $K_{osc} = v_m / v_C > 1.2$ for the coefficient of oscillation
- $t_N = 0.09 \div 0.16$ s for negative strip time
- $a_{max} < 3$ for the maximum acceleration of mould

- v_r = 2.3 ÷ 2.6 m/min for the relative velocity between the infusion of a mould
- TNS = 30 ÷ 35 % for negative strip time ratio

Oscillation parameters must satisfy two conditions affecting the quality of billet

Condition 1 - the length of the theoretical mark pitch OM cannot be greater than 25 mm, given that it increases the depth of character of the oscillating responsible for the formation of transverse cracks [9], which is why:

$$l_{OM} = (v_C / f_{osc}) < 25 \text{ mm} \quad (3)$$

where:

f_{osc} -oscillation frequency of mould (c/min)

v_C - casting speed (mm/min)

Condition 2 - Theoretical mark depth d_{OM} cannot exceed 400 µm, because increasing the risk of fractures transverse [9], which is why:

$$d_{OM} = 600\ (s / f_{osc})^{0.5} < 400\ \mu\text{m} \quad (4)$$

where:

s - mould stroke (cm)

f_{osc} - the frequency of oscillation cycle (Hz)

Step 3 - Identify the best conditions for lubrication of the billet

Mills in his work [10] concluded that there is a relationship between viscosityη and freezing point slag T_{sol}, and casting speed v_c and proposed the following empirical equation containing these components to determine the optimal lubrication (used powder):

$$Q_{s1} = 1.952 - 0.2461 \cdot v_C - 0.044 \cdot \eta - 0.00107 \cdot T_{sol} \quad (5)$$

To achieve proper lubrication conditions of the billet need to adjust the parameters of oscillation in relation to the characteristics of - mould powder (η, T_{sol}) and casting speed v_C to the species of the cast steel. These relationships were established by Kwon et al. in [11]. They have developed the following empirical formulas for steel:

Steel type A $$Q_{s2} = 0.74 \cdot (2 / s)^{0.3} \cdot (60 / f_{osc}) \cdot [\eta \cdot (v_C)^2]^{-0.5} + 0.17 \quad (6)$$

Steel type B and C $$Q_{s3} = 0.70 \cdot (2/s)^{0.3} \cdot (60/f_{osc}) \cdot [\eta \cdot (v_C)^2]^{-0.5} + 0.22 \quad (7)$$

Obtaining a good lubrication of the skin of the billet for equations (5) ÷ (7) is the condition [9]:

$$\mathbf{0.15 \le Q_s \le 0.45} \quad (8)$$

Step 4 - Classification of the billet/bloom/slab - setting the parameter R

In [12], based on analysis of the results of 30 devices CC operating in steel, obtained empirical dependence of consumption of slag Q_{s4} of the R - parameter, ie. surface to volume ratio of the billet/bloom/slab.

$$Q_{s4} = 2 / (R - 5) \quad (9)$$

where:

a - width of the mould (m)

b - thickness of the mould (m)

l_M - the length of the open mould (m)

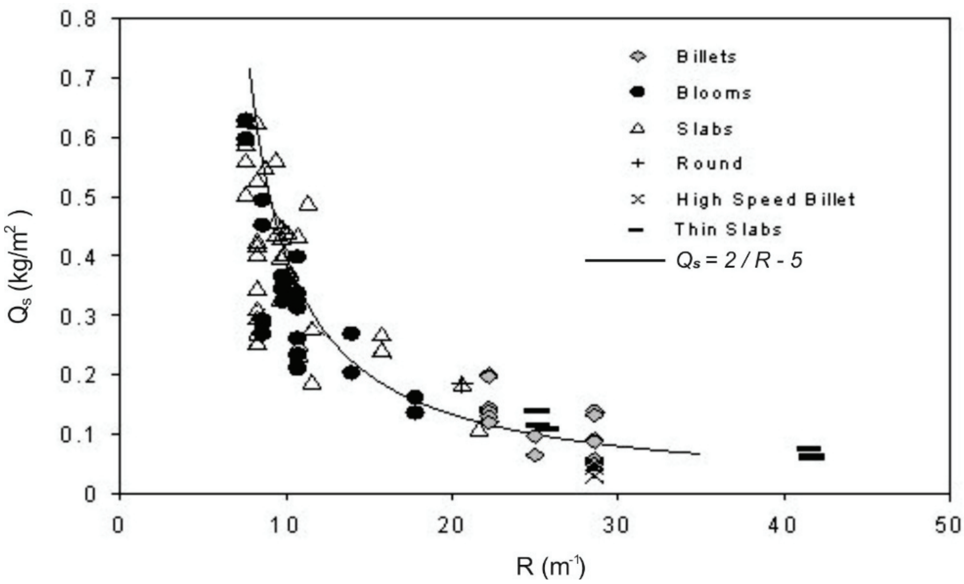

Figure 2 Powder consumption depending on the parameter R [12]

As shown in 2 powder consumption from largest to smallest is done in the following order:

slabs → blooms → billets → thin slabs

This order can be assigned to values for R and classify billet to the following division:

- **R < 10 slabs**
- **R = 10 ÷ 15 blooms**
- **R > 20 billets**
- **R > 30 thin slabs**

Consumption of mould powder (Q_s) is regulated by melting time of powder. Rate of speed of melting powders are controlled substantially by containing particles of free carbon ($\%C_{free}$), which are non-wetted by the slag and prevent the agglomeration of the liquid globule unless the carbon is oxidized. Therefore, the carbon content must be chosen so as to provide the required melting rate recycles. Analyzing the content of free carbon in mould powders offered on the market by different manufacturers, you can see the convergence of the size of the R parameter. It is logical observation that the larger cross-section of the billet including greater demand for liquid slag lubricating the skin of the billet. It also results in the need for speed melt dusting powders, which involves the reduction of the amount of free carbon in the chemical composition of mould powder.

Therefore, in this study it is assumed that the content of free carbon will be determined by the size of the parameter R, as shown in **Table 1**.

Table 1 The content of free carbon in mould powder depending on the value of the parameter R

Parameter R	1	2	3	4	5	......	......	......	......	47	48	49	50
$\%C_{free}$	0.5	1.0	1.5	2.0	2.5	......	......	......	......	23.5	24.0	24.5	25.0

Step 5 - Determination of selected physical parameters of mould powder

Table 2 contains the requirements to be met by the mould powder in terms of physicochemical properties, depending on the of the cast steel group.

Table 2 Selected physicochemical properties of the mould powder and technological parameters assigned to groups of steel.

Parameters	**Steel group**		
	Type A	**Type B**	**Type C**
Mould water flow rate (l / min)	mild	intense	normal
Dynamic slag viscosity; η (Puaz)	high	low	average
Basicity; C/S	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

The equations to calculate physicochemical parameters of mould powders

Dynamic viscosity of mould powder (η). Viscosity is calculated by Riboud model for three temperatures (1200 °C, 1300 °C and 1400 °C),

$$\eta = A \cdot T \exp (B / T) \quad (11)$$

where:

η - dynamic viscosity (Puaz)

T - temperature (K)

$$A = \exp [-19.1 + 1.73 \cdot [X_{CaO} + X_{MnO} + X_{MgO} + X_{FeO}] + 5.82\, X_{CaF2} + 7.02 \cdot [X_{Na2O} + X_{K2O}] - 35.76\, X_{Al2O3} \quad (12)$$

$$B = 31140 - 23896 \cdot [X_{CaO} + X_{MnO} + X_{MgO} + X_{FeO}] - 46356 \cdot X_{CaF2} - 39159 \cdot [X_{Na2O} + X_{K2O}] - 68333 \cdot X_{Al2O3} \quad (13)$$

where:

X - a molar ratio of components.

Basicity (C/S) - calculated the ratio of the oxides CaO / SiO_2

Liquidus temperature ($T_{liq.}$) of slag calculated by equation [6]:

$$T_{liq.} = 958 + 656.9 \cdot X_{SiO2} + 1040.7 \cdot X_{CaO} + 1343.2 \cdot X_{Al2O3} + 1090.5 \cdot X_{MgO} + 137 \cdot X_{Na2O} + 408.7 \cdot X_{LiO2} + 522 \cdot X_{FeO} + 760.9 \cdot X_{MnO} + 1022 \cdot X_{CrO} + 794 \cdot X_{Fe2O3} + 219 - 532 \cdot X_{CaF2} + 844 \cdot X_{TiO2} - 12.6 \cdot X_{B2O3} + 2234 \cdot X_{ZrO2} \quad (14)$$

Solidus temperature (T_{sol}) of slag calculated by equation [7]:

$$T_{sol.} = 1242\ °C - 2.15 \cdot X_{MgO} - 1.4 \cdot X_{Al2O3} - 4.5 \cdot X_{Na2O} - 8.5 \cdot X_{CaF2} - 6.4 \cdot X_{LiO2} - 15.3 \cdot X_{B2O3} \quad (15)$$

Break temperature (T_{br}) of slag calculated by equation [7]:

$$(T_{br} - 1120\ °C) = - 8.4 \cdot Al_2O_3\,\% - 3.3 \cdot SiO_2\,\% + 8.65 \cdot CaO\,\% - 13.8 \cdot MgO\,\% - 18.4 \cdot Fe_2O_3\,\% - 3.2 \cdot MnO\,\% - 9.2 \cdot TiO_2\,\% - 2.1 \cdot K_2O\,\% - 3.2 \cdot Na_2O\,\% - 6.47 \cdot F\,\% \quad (16)$$

The amount of the crystalline phase of slag (NBO/T) specified b. formula:

$$NBO/T = \frac{2\,X_{CaO} + 2\,X_{BaO} + 2\,X_{CaF2} + 2\,X_{Na2O} + 2\,X_{Al2O3} + 6\,X_{Fe2O3} + (2\,X_{MgO} + 2\,X_{MnO})}{X_{SiO2} + 2\,X_{Al2O3} + X_{TiO2} + 2\,X_{B2O3} + (X_{MgO} + X_{MnO})} \quad (17)$$

where:

X - a molar ratio of slag components.

The thermal conductivity of mould powder (k_{sys}). Holzgruber et al. [8] brought out on the basis of experiments carried out, the equation for the total thermal conductivity of the system as a function of the chemical composition of mould powder, (W / m K):

$$k_{sys.(1200°C)} = 2.03 - 0.459 \cdot ((“CaO“ \% / “SiO_2“ \%) + B_2O_3 \%) - 0.1695 \cdot FeO \% - 0.0348 \cdot Al_2O_3 \% \quad (18)$$

where:

$”CaO” \% = CaO \% + MgO \% + MnO \% + Na_2O \% + LiO_2 \%$

$“SiO_2” \% = SiO_2 \% + B_2O_3 \%$

3. DESIGN OF CHEMICAL COMPOSITION OF MOULD POWDER

Designing the chemical composition of the mould powder for a particular grade of steel and the cross-section of the billet run based on conversion parameters in **Table 2** in sequence:

- determine the ratio of two basic oxides: CaO (25 ÷ 45 %) and SiO_2 (28 ÷ 48 %) in order to calculate the basicity C/S of mould powder, in accordance with the criteria adopted in **Table 2**,
- hat compose the contents of: Al_2O_3 (0 ÷ 17 %), CaF_2 (4 ÷ 21 %), MgO (0 ÷ 10 %), Na_2O (1 ÷ 27 %), LiO_2 (0 ÷ 4 %), B_2O_3 (0 ÷ 10 %), FeO (0 ÷ 6 %), MnO (0 ÷ 10 %), TiO_2 (0 ÷ 5 %), in order to calculation results: a dynamic viscosity (η_{1300}), break temperature(T_{br}), the liquidus temperature ($T_{likw.}$) and the solidus ($T_{sol.}$), ratio of temperature break temperature / viscosity (T_{br} / η), thermal conductivity of powder ($k_{sys.(1200°C)}$), the quantity of the crystalline phase of the slag (NBO/T), as close as possible to values established in **Table 2**,
- the last component is to determine the content of free carbon of mould powder whose value is chosen from **Table 1** based on the calculation of the parameter R.

4. CONCLUSION

The article presents a concept model for the design of the chemical composition of the mould powder based on the developed in recent years, empirical equations. The calculations using the data cited in the literature lead to the conclusion that using the developed model properly you can design the chemical composition of mould powder species for carbon steel and low-alloy cast at standard speeds in slabs and a large diameter > 160 mm. Due to the smaller amount of data in the literature for smaller formats of billets (billet and thin slabs), developed a model overestimates the value of the established dynamic viscosity (equation 14), the consequence of which may be incorrectly assessed the contents of alkaline oxides in the chemical composition of mould powder. Empirical formulas on which the model for this group of billets need to be refined is based on the industrial experience.

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