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The impact of the chemical composition of continuous casting moulds on their physical properties

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Properties

ABSTRACT

Purpose: The purpose of the research conducted was to determine the impact of a binder used in selected mould powders in continuous casting mould on the following physical properties: viscosity, alkalinity and the melting point. Additionally, non-fluoric casting powders were analyzed.
Design/methodology/approach: The methodology of the research conducted was based on the chemical analysis of basic mould powders and powders with 5% addition of food origin binder.
Findings: The findings indicate that the addition of the binder results in decreasing in viscosity in the cases studied.
Research limitations/implications: The physical properties of mould powders have an impact on the quality of continuous ingot, therefore it is necessary to be acquainted when searching for the relationship between the quality of the casting and technological parameters of steel continuous casting process.
Practical implications: The findings may be applicable in technological practice when changing standard mould powder for mould in the form other than a powdered one, in which food origin binders are used.
Originality/value: Modified mould powders are an alternative for standard powdered mould, therefore it is desirable to conduct research on their properties in order to plan and manage steel continuous casting process in a proper way.
Keywords: Mould powder; Organic binder; Physical properties

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1. Introduction

Currently the requirement of the highest efficiency concerning all processes of production is set, and as far as products are concerned, maintaining constant properties and characteristics if possible. These demands have special justification in metallurgical industry due to high costs of technical devices installation and manufacturing costs. In such conditions, continuous processes have become important, because they provide the opportunity to take advantage of maximum production capacity of the devices, the possibility of mechanization, automation and computerization of the process, as well as stabilization of the property of a manufactured product by the stabilization of conditions in the process. Continuous casting of steel is one of these processes, which has particularly developed for the last several dozen years.

Excellent production and economical effects of continuous casting cannot draw attention away from the fact that even this advanced material technology has been still developing and not all capabilities of the process of securing the ingot against defects formation have been exhausted.

Mould powders play a key role in the steel continuous casting process, and, to a considerable extent, they are responsible for the quality of the ingot received. Therefore, all studies on the desired properties of applied powders are becoming more and more significant.

Effective mould powders should perform the following functions:

- protect the meniscus of liquid steel against oxidation,
- lubricate the cast band,
- provide optimal horizontal exchange of heat for the grade of steel cast,
- absorb non-metallic inclusions from liquid steel.

It is possible to properly perform these functions having selected the adequate properties of the mould powders e.g. density, dynamic viscosity, surface tension, wettability, melting point, softening and flow. Many of these physical properties depend on the chemical composition of the mould powder.

This paper presents the research on the impact of the chemical composition of lubricating and insulating continuous mould powders on their selected physical properties and on the impact of replacing fluorine with boron compounds in the chemical composition of casting powders on the steel produced.

2. Physical and chemical properties of mould powders and their impact on the quality of cast steel

The steel cast into the continuous steel casting mould is covered with a layer of casting powder. During the whole process of casting the thin layer of slag, which is formed of melt mould powder, without separating from the surface of steel, flows off over its meniscus between the skin of solidifying ingot and the wall of the continuous casting mould. Therefore, there is no direct connection between the steel and walls of the continuous casting mould [1]. In the process of casting the mould powder gradually changes including partial decomposition, lumping, sintering and melting.

The functions fulfilled of mould slag depends on the following physical and chemical properties:

- chemical and mineralogical composition,
- humidity,
- loss of ignition,
- bulk density,
- grain composition,
- temperatures: refraction T_{br}, melting and flow,
- melting rate,
- dynamic viscosity.

The behaviour of mould powders on the steel surface depends mainly on the flow temperature value. The difference in temperatures, and thus the temperature interval is an important indicator as well. It maps the probability of forming homogeneous or heterogeneous slags. Mould powders used in continuous casting moulds with very extensive temperature interval, especially in the case of less stabilized mirror of metal in the continuous casting mould, predispose to form excessive “stag border”, and, in consequence, it may lead to a defect - rupture of the skin or leakage. Melting and flowing temperatures of continuous casting mould depend on its chemical and mineralogical composition and grade and purity of metallurgical casting steel or greater “shift” of these temperatures. Melting rate is a very significant property of mould powders. This property decides, to what degree the basic function of the casting powder will be ensured in given conditions-guaranteeing of the optimal quantity of lubricating factor on the steel mirror of the continuous casting mould, ensuring a regular, fluent feeding of the fissure between the skin of the solidifying ingot and the continuous casting mould. Viscosity of mould stags is considered to be one of the most important qualities by both producers and users. The mould powder should demonstrate such dynamic viscosity to guarantee perfect lubrication of the adjacent surfaces of solidifying ingot and continuous casting mould in the largest possible distance from the steel mirror to the casting direction. Table 1 presents the effect of chemical compounds included in mould powders on the selected physical properties.

Table 1.
The effect of chemical compounds included in mould powders on the selected physical properties

Component	Property		
	Viscosity	T_{br}	T_{sol}
CaO	–	+	+
SiO_2	+	–	–
Al_2O_3	+	–	–
MgO	–	–	–
$Na_2O + K_2O$	–	–	–
FeO	–	–	
CaF_2	–	–	–
MnO	–	–	–
B_2O_3	–	–	–
ZrO_2		+	+

where:
T_{br} = 1393 K - %MO (max. 1393 K)
T_{sol} = 1515 K – x(MO) (max. 1515 K)
x – mole fraction;
MO – oxide
\+ increase
\- decrease

The basic task of the mould powder is to lubricate the forming steel skin. Improper lubrication may lead to various ingot defects and loss of control over casting process. Typical defects effected by mould powder are presented in Table 2 [2].

Table 2.
Ingot defects connected with mould powder and their causes [2]

Defect	Cause of the defect
Star-shaped cracks	Solidification of a mould stag in the lower part of the continuous casting mould (irregular transfer of heat) - improper T_{br}
Deep oscillatory marks	Improper viscosity of a liquid mould slag.
Transverse cracks and cracks of the corners	Too little usage of a mould powder.
Leakage caused by delamination	Lack of lubrication. Forming low-melting skin as a result of carbon impurity. Lack of thin, glassy stag film of low T_{br}.
"Silver" contractions	Al particles$_2$O$_3$ getting out with the steel from cast intercepted by the skin
Depressions	When starting and continuous mould powders are mixed, they form the so-called "stag border" (the mixture of pasty and parched stag), which forms a washer for cavings-depressions, at the point of upper stroke of the continuous casting mould. It stops the flow of the thin stag, the "frame" melts and it is intercepted by the skin.
Erosion of SEN cast	Erosion of cast made by the stag caused by: • low viscosity of mould powders, • CaO attacking against stabilized ZrO_2 by CaF_2 and SiO_2.

3. Author's own research

The following samples were used to determine the physical properties of casting powders: commercial powder (basic powder-A) and samples in the form of briquet made of basic powder with 5% addition of various binders (powders B, C and D). The binders used to bind the powder were the waste products of food industry. The inconvenience of applied powders is connected with excessive dustiness aggravating working conditions, leading to material losses and their tendency to absorb humidity from the environment and lumping during storage and casting in the continuous casting mould. Mould powders in the form of homogeneous layer covering the steel mirror in the continuous casting mould are to ensure typical functions, as well as providing proper thermal insulation, proper lubrication and absorbtion of non-metallic inclusions. The aim of these factors is to eliminate, partially or completely, the aforementioned inconveniences connected with the use of the powders [3].

In order to determine the applicability of mould powders formed with the use of water or a binder, the following properties were specified:

- chemical composition,
- alkalinity,
- dynamic viscosity,
- melting point,
- temperature interval.

Table 3.
Chemical composition of studied mould powders

% by mass \ Mould powder	A	B	C	D
Al_2O_3	5.01	4.46	4.71	4.51
B_2O_5	0.016	0.019	0.035	0.026
C	8.49	10.13	7.64	8.29
CaF_2	17.16	16.88	14.61	16.38
CaO	16.45	14.16	16.69	14.93
Fe_2O_3	1.23	1.56	1.30	1.06
FeO	0.54	1.27	1.27	1.27
K_2O	0.66	0.63	0.86	0.65
MgO	1.54	1.43	1.60	1.50
MnO	0.02	0.04	0.04	0.03
Na_2O	14.64	13.96	13.81	14.35
SiO_2	29.40	26.56	26.16	27.40
TiO_2	0.21	0.19	0.20	0.19
CaO/SiO_2	0.56	0.53	0.64	0.54
$(CaO + MgO)/SiO_2$	0.61	0.59	0.70	0.60

Chemical composition of the powders studied, as well as their alkalinity is presented in Table 3.

The addition of a binder causes certain, but slight changes in the chemical composition of the powders expressed by percentage share. The addition of a binder causes decrease in the content of Al_2O_3, CaF_2, Na_2O and SiO_2 and increase in the content of B_2O_5, C, CaO (with the exception of C casting powder), FeO and MnO. The content of the remaining components in the powders studied altered only slightly, without distinct regularity, increase or decrease. The chemical composition of mould powders, particularly the percentage shares of calcium and silicon oxides affect the alkalinity of a mould slag. The alkalinity of slag affects therefore its physical properties, especially the refraction temperature and viscosity. The alkalinity of studied mould powders was calculated on the basis of the results of chemical composition analysis. The alkalinity of studied samples is presented in Table 3. Acquired alkalinities of the samples indicate minor differences in this parameter between particular samples. Alkalinity, calculated according to CaO/SiO_2 ranges from 0.53-0.64, whereas calculated according to $(CaO+MgO)/SiO_2$ ranges from 0.59-0.70; The C casting powder is characterized by the highest alkalinity. Differences in alkalinity between particular powders studied are so little, that they should not affect the behaviour of the mould powder in the continuous casting mould.

Riboud estimate method [4] was used to study the dynamic viscosity of given powders on the basis of the following relationship:

$$\eta = T \cdot e^{(B/T)+A} \quad (1)$$

where:
η - dynamic viscosity, Pa·s
T – temperature, K
X - mole fraction of components

$$A = e^{\left(\begin{array}{l}-19{,}81+1{,}73\cdot\left(X_{CaO}+X_{MnO}+X_{MgO}+X_{FeO}\right)\\+5{,}82\cdot X_{CaF_2}+7{,}02\cdot\left(X_{Na_2O}+X_{K_2O}\right)\\-35{,}76\cdot X_{Al_2O_3}\end{array}\right)} \quad (2)$$

$$B = 31140 - 23896\cdot\left(\begin{array}{l}X_{CaO}+X_{MnO}+X_{MgO}\\+X_{FeO}\end{array}\right) - 46356\cdot X_{CaF_2} - 39159\cdot\left(X_{Na_2O}+X_{K_2O}\right) + 68833\cdot X_{Al_2O_3} \quad (3)$$

The results for the dynamic viscosity of the powders for 1473 K, 1573 K and 1673 K temperatures are presented in Fig. 1.

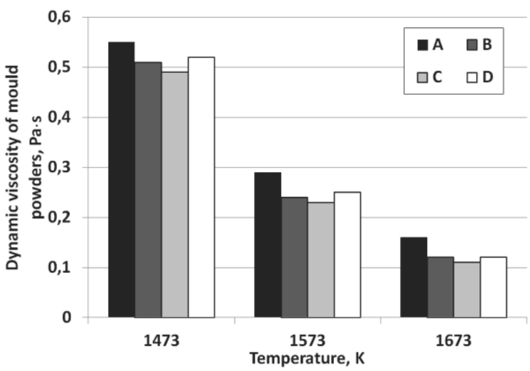

Fig. 1. Dynamic viscosity of mould powders

A powder shows the highest dynamic viscosity in all temperatures. The addition of the binder causes a slight decrease in the dynamic viscosity. The binder type has little effect on the dynamic viscosity of the powders studied. In the terms of dynamic viscosity, all the samples studied are located within the technologically recommended range for the mould powders and they amount 0.05-0.6 Pa·in temperature 1573 K.

Next, the melting point and the temperature interval for a powder with the addition of a binder were studied. The results are presented in Table 4.

Table 4
Melting points, temperature interval of the powders studied

	Mould powder			
	A	B	C	D
Melting points, K	1323	1333	1323	1373
Temperature interval, K	80	60	30	25

The results obtained indicate that the binder added to the continuous casting mould does not cause the increase in the melting point or causes little of it. D powder has the highest melting point.

Temperature interval is a significant characteristic of mould powders. Powders with large temperature interval, especially in the case of less stabilized mirror of the metal in the continuous casting mould, display a tendency to form excessive "stag border", and, as a consequence, it may lead to a defect, even to a rupture of the skin [2]. Therefore, this indicator should be as low as possible. The temperature interval was the greatest for A powder of all the powders studied. The samples with added binder indicate the temperature interval from 25% to 68.75% lower than the base sample [5].

4. Summary

Summarizing the findings of the research conducted on the effects of chemical composition of mould powders on their physical properties it may be stated that:

1. The alteration of the chemical composition of the mould powder by addition of an organic binder (in order to form a compressed layer) did not cause alteration in alkalinity and the melting point, but caused a slight decrease in dynamic viscosity. The higher temperature the less pronounced are the differences in dynamic viscosity properties. The addition of a binder causes a 25-68.75% decrease in the temperature interval in comparison with the base powder.
2. Application of the mould powder in the form of a compressed layer acquired by binder addition eliminates dustiness and material losses of the powders involved, improves working conditions and removes inconveniences connected with powder lumping in the continuous casting mould, therefore limiting the formation of surface defects of continuous ingots.
3. Studies on the chemical composition of the mould powders modification are justified as they indicate the possibility to obtain powders, which should both be convenient in application (dusty powders) and display better properties, such as lower temperature interval, by adding an organic binder.

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