ANNALS OF THE FACULTY OF ENGINEERING HUNEDOARA

2005, Tome III, Fascicole 3

MATHEMATICAL INTERPRETATION IN THE AREA OF CONTINUOUS CASTING REGARDING THE SYNTHETIC SLAGS VISCOSITY

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KEY WORDS
steel, continuous casting, lubrication, slags, viscosity

SHORT ABSTRACT

The continuous cast semifinished products quality is in a major part influenced by the lubrication process from the mould which is influenced at its turn by slag viscosity resulted from the melting of the lubrication powders.

In the paper it is analysed the chemical composition influence on slag viscosity.

1. INTRODUCTION

The efficiency of steel continuous casting is determinate in addition to technological factors by the using of the slag powdery mixtures for steel protection in crystalliser tanks of the continuous casting devices.

The mixtures have the following functions [*1, 2, 3*]:

- ensure the lubrication between the walls of the crystalliser tank and the solidified steel crust;
- retain a part of the non-metallic inclusions, which decant at the interface metal-slag;
- improve heat transfer from the surface of the half-finished product to the crystalliser tank walls;
- ensure thermal insulation of the liquid steel surface and protect it against excessive cooling;
- ensure high quality of the surface of the half-finished product cast with high speed.

These functions can be ensured by a proper choosing of the materials componing the lubricating flux, with certain physical and chemical properties.

The main properties of lubricating flux are:

- melting range and melting rate;

- viscosity;
- crystallising temperature and vitrification temperature.

Melting range of synthetic flux is recommended to be greater, because in this way slag film seeped between crust and crystalliser tank remain liquid and ensure a better lubrication.

Lubrication efficiency depends on slag viscosity, which is mainly influenced by chemical composition and temperature. As long as slag remains liquid its yielding properties are determinate by the viscosity curve.

2. EXPERIMENTATION AND RESULTS

The main types of slag mixtures belong to ternary systems: SiO_2-Al_2O_3-CaO, SiO2-Al_2O_3-FeO, SiO_2-Al_2O_3-Na_2O.

This paper presents the results obtained processing the experimental dates related to slag viscosity (η) - function on chemical composition. It was studied slags from the system SiO_2-Al_2O_3-CaO-MgO for which there were determinate chemical composition and viscosity at 1350^0C. In *Table I* the main chemical composition of the studied slags are presented. Also, in *Table I*, the experimentally and the theoretically values of the viscosity are presented.

The values processing were made using MATLAB calculation program. Using this calculation program we determinate a correlation of the following form:

$$\eta = 0{,}009701\cdot(CaO)^2 + 0{,}04493\cdot(MgO)^2 + 11{,}37\cdot(Al_2O)/(SiO_2)^2 + 0{,}07406\cdot(CaO)\cdot(MgO) - 0{,}6481\cdot(MgO)\cdot(Al_2O_3)/(SiO_2) - 0{,}09657\cdot(Al_2O_3)/(SiO_2)\cdot(CaO) - 1{,}705\cdot(CaO) - 3{,}942\cdot(MgO) - 4{,}798\cdot(Al_2O_3)/(SiO_2) + 65{,}51 \quad [1]$$

The correlation coefficient has the value $R = 0{,}8794$ and the deviation from the regression surface is $S = 3{,}438$.

This surface in the four-dimensional space admits a saddle point of coordinates:

$(CaO)_s = 44{,}97\%$; $(MgO)_s = 12{,}22\%$; $(Al_2O_3)/(SiO_2)_s = 0{,}7503$,
to which the corresponding value of viscosity is $\eta_s = 1{,}296$.

The existence of a saddle point inside the technological domain has a particular importance as it ensures stability to the process in the vicinity of this point, stability which can be either preferable of avoidable.

The behaviour of this hyper surface in the vicinity of the stationary point (when this point belongs to the technological domain) or in the vicinity of the point where the three independent variables have their respective mean value, or in a point where the dependent function reaches its extreme value in the technological domain (but not being a saddle point) can be rendered only as a table, namely, assigning values to the independent variables on spheres which are concentrically to the point under study.

TABLE I. THE EXPERIMENTAL AND THE THEORETICALLY VALUES

No.	CaO [%]	MgO [%]	Al_2O_3/SiO_2 [-]	$\eta_{experimental}$ [poise]	$\eta_{teoretically}$ [poise]	Error [-]
1.	23.5	0	0.2	30	29.85	0.1537
2.	27.5	0	0.2	22	24.93	-2.929
3.	32.5	0	0.2	14	19.22	-5.218
4.	42.5	0	0.2	6.5	9.252	-2.752
5.	50	0	0.2	2.5	3.052	-0.5515
6.	32.5	0	0.25	32	19.08	12.92
7.	37.5	0	0.25	10	13.83	-3.828
8.	45	0	0.25	5	6.863	-1.863
9.	50	0	0.25	2.5	2.826	-0.326
10.	35	0	0.33	18	16.27	1.735
11.	40	0	0.33	8	11.22	-3.219
12.	45	0	0.33	5	6.659	-1.659
13.	50	0	0.5	3	2.551	0.4491
14.	32.5	0	0.5	21	19.22	1.775
15.	40	0	0.5	10	11.35	-1.351
16.	45	0	0.5	5	6.708	-1.708
17.	50	0	0.5	7	2.551	4.449
18.	35	0	1	35	20.92	14.08
19.	40	0	1	10	15.55	-5.547
20.	45	0	1	5	10.66	-5.663
21.	50	0	1	7.5	6.264	1.236
22.	26.5	5	1	17	19.14	-2.141
23.	35	5	1	6	12.05	-6.048
24.	45	5	1	5	5.498	-0.4979
25.	30	5	0.33	15	13.25	1.752
26.	40	5	0.33	8	6.374	1.626
27.	50	5	0.33	5.5	1.441	4.059
28.	45	5	0.2	5	4.492	0.5082
29.	50	5	0.2	2.5	2.331	0.1695
30.	30	10	1	6	7.578	-1.578
31.	36	10	1	5	5.055	-0.05502
32.	45	10	1	4.5	2.58	1.92
33.	50	10	1	2.3	1.884	0.4163
34.	22.5	10	0.5	5	9.915	-4.915
35.	30	10	0.5	4	6.14	-2.14
36.	40	10	0.5	3	2.806	0.1944
37.	50	10	0.5	2.1	1.411	0.6887
38.	26	10	0.33	8	8.758	-0.7575
39.	32	10	0.33	8	6.157	1.843
40.	40	10	0.33	3.5	3.776	-0.2756
41.	50	10	0.33	4.5	2.545	1.955
42.	32.5	10	0.25	8	6.597	1.403
43.	40	10	0.25	3.5	4.459	-0.9594
44.	50	10	0.25	2.2	3.307	-1.107
45.	27	10	0.2	10	9.297	0.7025
46.	35	10	0.2	5	6.241	-1.241
47.	45	10	0.2	4.5	4.166	0.3341
48.	50	10	0.2	8	3.856	4.144
49.	22.5	15	1	4.5	2.711	1.789
50.	35	15	1	3.5	1.052	2.448
51.	45	15	1	2.1	1.908	0.1919
52.	22.5	15	0.5	1.1	2.531	-1.431
53.	35	15	0.5	1.15	1.476	-0.326
54.	45	15	0.5	2	2.814	-0.8144
55.	52	15	0.5	4.5	4.906	-0.4058
56.	25	15	0.33	6	3.352	2.648
57.	35	15	0.33	3.5	2.915	0.5853
58.	45	15	0.33	2.05	4.417	-2.367
59.	32	15	0.25	6	3.724	2.276
60.	40	15	0.25	4.5	4.367	0.1334
61.	50	15	0.25	2	6.917	-4.917

As this surface cannot be represented in the three-dimensional space, we resorted to replacing successively one independent variable by its mean value. Thus, we obtained the following equations:

$$\eta_{CaO\ med} = 0{,}04493\cdot(MgO)^2 + 11{,}37\cdot(Al_2O_3)/(SiO_2)^2 + 0{,}6481\cdot(MgO)\cdot(Al_2O_3)/(SiO_2) - 1{,}047\cdot(MgO) - 8{,}573\cdot(Al_2O_3)/(SiO_2) + 13{,}68 \quad [2]$$

$$\eta_{MgO\ med} = 11{,}37\cdot(Al_2O_3)/(SiO_2)^2 + 0{,}009701\cdot(CaO)^2 - 0{,}09657\cdot(Al_2O_3)/(SiO_2)\cdot(CaO) - 9{,}313\cdot(Al_2O_3)/(SiO_2) - 0{,}09657\cdot(Al_2O_3)/(SiO_2)\cdot(CaO) - 9{,}313\cdot(Al_2O_3)/(SiO_2) - 1{,}189\cdot(CaO) + 40{,}23 \quad [3]$$

$$\eta_{Al2O3/SiO2\ med} = 0{,}009701\cdot(CaO)^2 + 0{,}04493\cdot(MgO)^2 + 0{,}07406\cdot(CaO)\cdot(MgO) - 1{,}752\cdot(CaO) - 4{,}255\cdot(MgO) + 65{,}85 \quad [4]$$

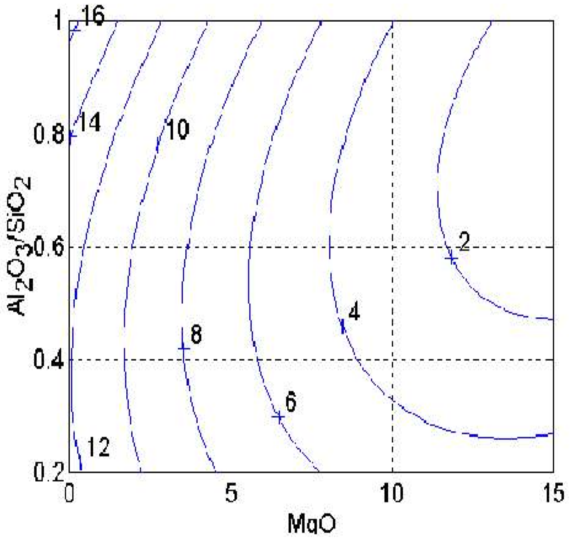

Figure 1. The correlation level lines $\eta = f(CaO_{med}, MgO, Al_2O_3/SiO_2)$

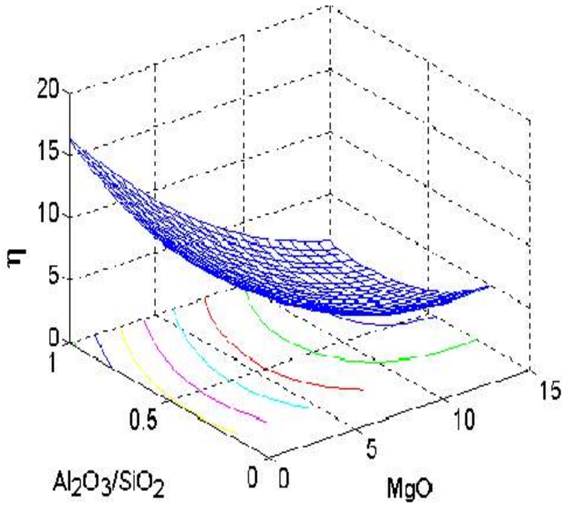

Figure 2. Surface $\eta = f(CaO_{med}, MgO, Al_2O_3/SiO_2)$

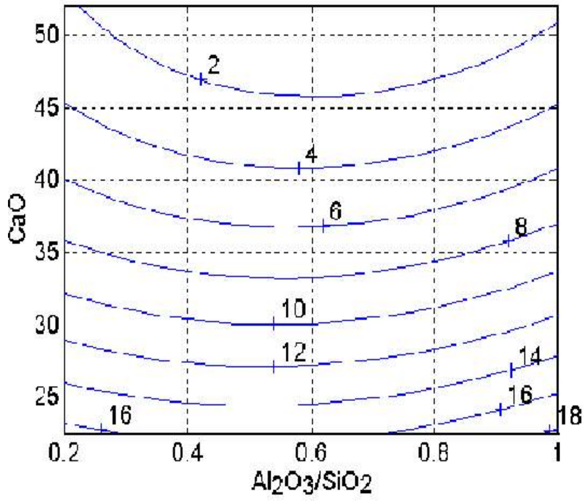

Figure 3. The correlation level lines $\eta = f(CaO, MgO_{med}, Al_2O_3/SiO_2)$

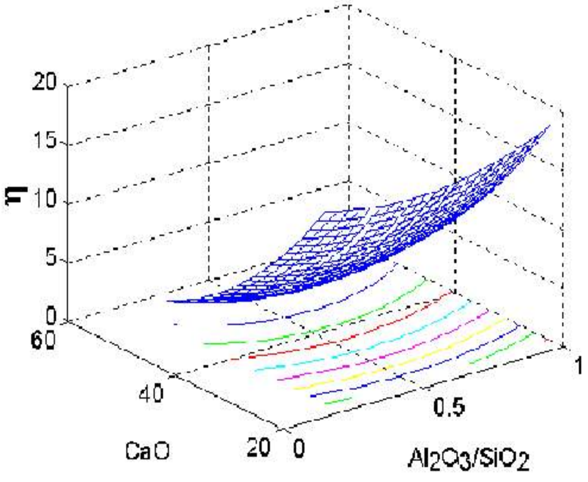

Figure 4. Surface $\eta = f(CaO, MgO_{med}, Al_2O_3/SiO_2)$

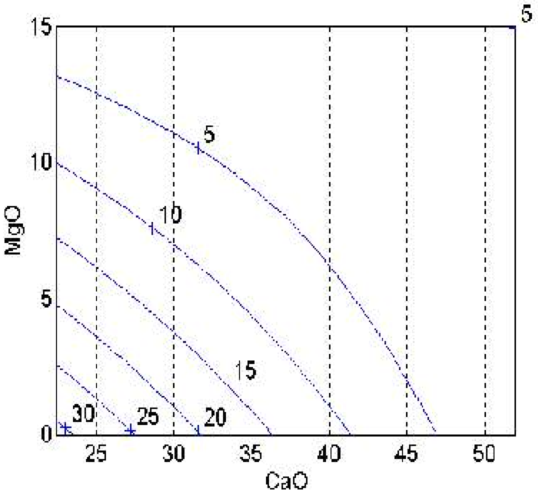

Figure 5. The correlation level lines η = f (CaO, MgO, $Al_2O_3/SiO_{2\ med}$)

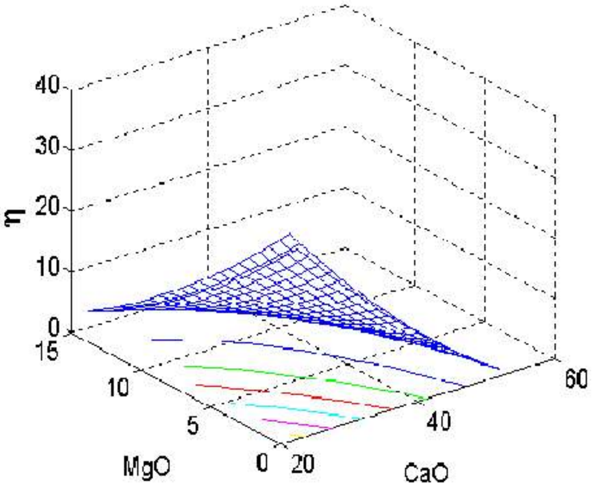

Figure 6. Surface η = f (CaO, MgO, $Al_2O_3/SiO_{2\ med}$)

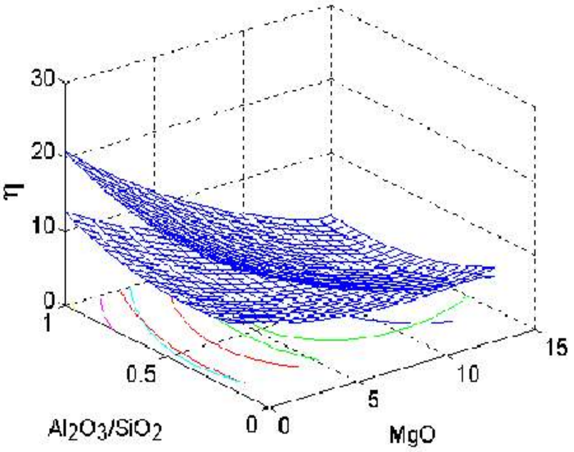

Figure 7. Representation of grade volume for CaO within $CaO_{med}\cdot 0.9$ and $CaO_{med}\cdot 1.1$

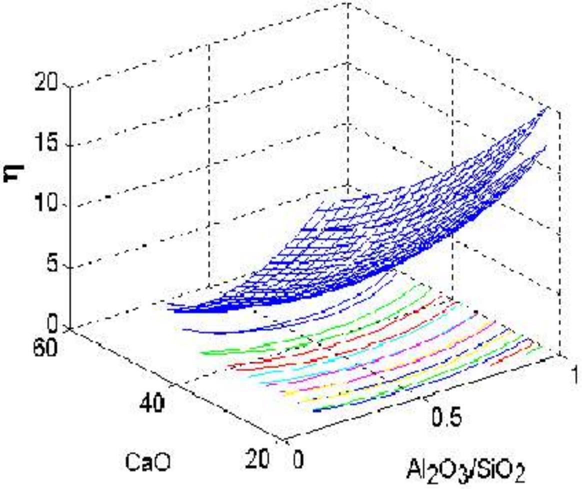

Figure 8. Representation of grade volume for MgO within $MgO_{med}\cdot 0,9$ and $MgO_{med}\cdot 1,1$

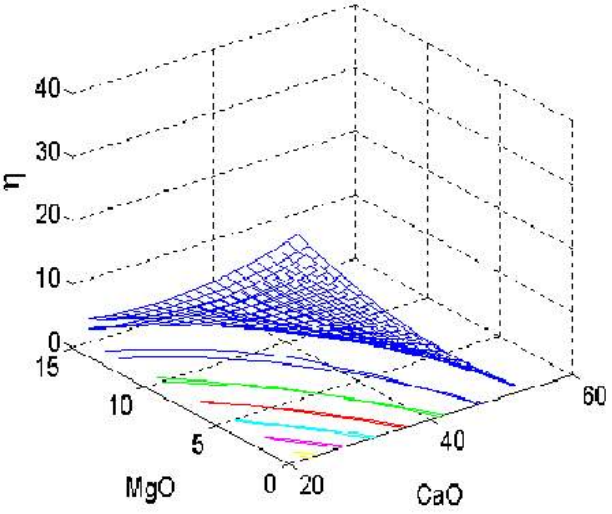

Figure 9. Representation of grade volume for Al_2O_3/SiO_2 within $Al_2O_3/SiO_{2\ med}\cdot 0.7$ and $Al_2O_3/SiO_{2\ med}\cdot 1,3$

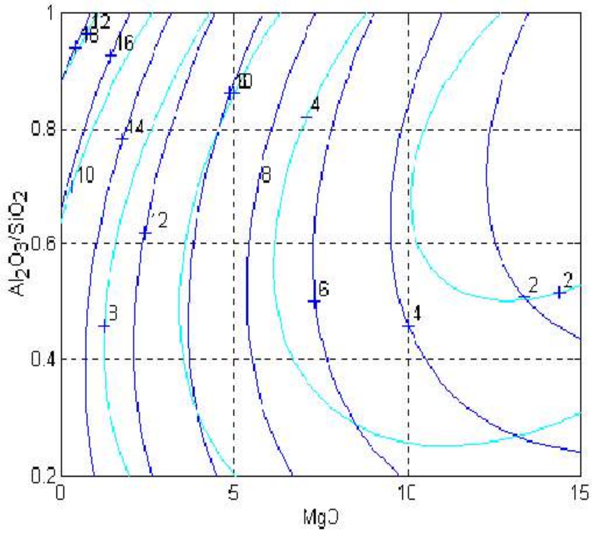

Figure 10. The level lines for variation volume for Al_2O_3/SiO_2 and MgO

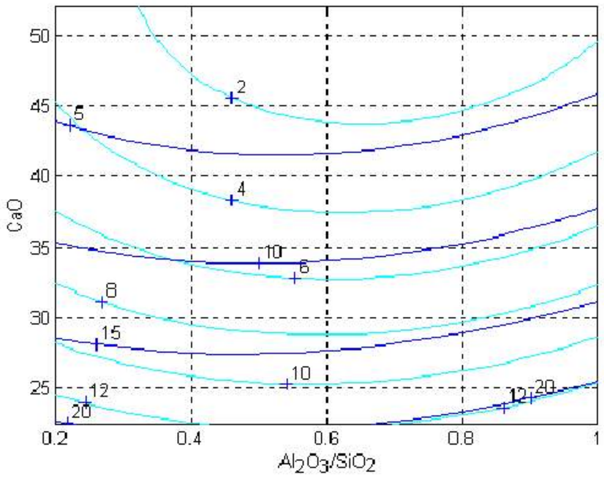

Figure 11. The level lines for variation volume for CaO and Al_2O_3/SiO_2

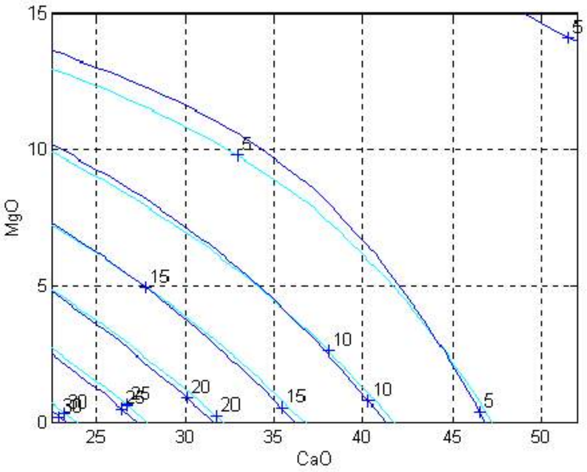

Figure 12. The level lines for variation volume for MgO and CaO

These surfaces, belonging to the three-dimensional space can be reproduced and therefore interpreted by technological engineers. These surfaces are represented in figures 1, 3 and 5.

In order to have as accurate a quantitative analysis as possible we showed in figures 2, 4 and 6 the corresponding level lines, which lead to the following conclusions:

- in case $CaO = CaO_{med}$, η is maximum for low values of MgO and minimum for MgO ≈ 15% and $Al_2O_3/SiO_2 \approx 0{,}8\%$;
- in case $MgO = MgO_{med}$, η is maximum for CaO ≈ 25% and minimum for CaO ≈ 45%;
- in case $Al_2O_3/SiO_2 = Al_2O_3/SiO_{2\ med}$, η is maximum for CaO ≈ 25% and MgO minimum and, respectively, takes minimum values for CaO ≈ 50% and MgO ≈ 15%.

Knowing these level curves allows the correlation of the values of the two independent variables so that we can obtain a viscosity within the required limits. If in equation [1], instead of assigning the mean value to an independent variable, we assign it two values, namely the mean value to which we add, respectively deduct one third of the mean square deviation of this variable, we obtain in the space a domain limited by these surfaces, as well as by the technological limitations of the other two independent variables. In this way we obtained the figures 7, 8 and 9, corresponding to them, the level lines of the two extreme surfaces, shown in figures 10, 11 and 12.

Knowing these volumes allows technological engineers to correlate more loosely the three independent variables in order to obtain a clear-cut zone, leading to a constant viscosity, of desired value.

3. DISCUSSION

During the experiments we used original recipes for lubricating. To produce the powders we used different materials, including industrial wastes, in the following percentage:

- thermal power station dust concentrate: 15...20%;
- termoplast cellular concrete wastes: 12...16%;
- furnace slag: 24...28%;
- raw fluorine: 5...6%;
- graphite (powders): 20...23%;
- limestone: 6...10%;
- soda: 5...6%;
- dolomite: 3...4%.

Industrial research has been performed to obtain a number of 8 (eight) charges, cast in bloom form (240x270 mm) at a 4 (four) wire equipment (experimental wires) and has been compared with one standard wire which use standard lubricating powders (scorialit type C163-79/H). In TABLE II the main characteristics of the studied powders are presented. Also the main chemical composition, the proportion and the variation limits are presented. The experimented powders have been good behaviour, similar with the standard powder. To obtain the desirable viscosity the composition of the powder production recipes is modified.

TABLE II. THE CHEMICAL COMPOSITION, THE PROPORTION, THE MAIN CHARACTERISTICS AND THE AREA OF PERCENTUAL VARIATION OF THE COMPONENTS IN THE USES LUBRICATING POWDERS

		VARIATION AREA, [%]	
CHEMICAL COMPONENTS	SiO_2	24.62…27.64	
	CaO	20.30…24.88	
	MgO	1.40…1.70	
	Al_2O_3	8.30…12.20	
	Fe_2O_3	4.71…6.42	
	CaF_2	5.77…9.58	
	P_2O_5	0.10…0.14	
	Na_2O	4.31…4.75	
	K_2O	0.35…0.42	
	TiO_2	0.16…0.20	
	MnO	0.51…0.57	
PROPERTIES	specific weight	0.7…0.9 g/cm^3	
	softening point temperature	1150…1210^{0}C	
	melting temperature	1240…1285^{0}C	
	lubricating temperature	1300…1350^{0}C	
	granulometric analyses	screen size, [mm]	screenings, [%]
		0.5	all > 0.5
		0.125	2.0…10.0
		0.06	10.0…30.0

Mathematical simulation allows determining the medium values of the basic components of the slag, in order to obtain a necessary value for the viscosity. Therefore, we suggest a mathematical interpretation of the influences of the main components over the viscosity, through the triple correlations theory in the MATLAB area. For independent variables the CaO, MgO, and the Al_2O_3/SiO_2 ratio are considered, and the viscosity is the dependent parameter. We searched for a method of molding the dependent variables depending on the independent variables x, y, z:

$$u = c_1 \cdot x^2 + c_2 \cdot y^2 + c_3 \cdot z^2 + c_4 \cdot x \cdot y + c_5 \cdot y \cdot z + c_6 \cdot z \cdot x + c_7 \cdot x + c_8 \cdot y + c_9 \cdot z + c_{10} \quad (1)$$

In the chapter "2. EXPERIMENTATION AND RESULTS" of this paper, there are shown the results of the multidimensional processing of experimental data using the MATLAB calculation and graphical program.

4. CONCLUSIONS

The researches we carried out have lead to the following conclusions:

- the viscosity of the slag resulting from melting the lubricating powder is influenced by its chemical composition;
- using the MATLAB calculation programs we determined correlations between viscosity and chemical composition indices, expressed both graphically and analytically;
- knowing the double and triple correlations is really helpful in practice, as it allows us to determine variation boundaries for the indices of slag chemical composition, in view of obtaining the desired values of viscosity [4];
- the usage of these programs can also be extended to the study of other slag characteristics.

We consider that it would be interesting and useful for practice knowledge of these triple correlations between viscosity and the powder constituents, which would allow a safer adjustment of the recipe constitution. The usage of this theory and the mathematical interpretation in MATLAB area, can also be extended to the study of influences other components of the slags, and can be presented other level curves and regression surfaces from the continuous casting practice and engineering technological interpretation. This is the opinion of the Romanian technologists.

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