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PROCEEDINGS BOOK

19th INTERNATIONAL FOUNDRYMEN CONFERENCE

Humans - Valuable Resource for Foundry Industry Development

Split, June 16th – 18th, 2021

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19th INTERNATIONAL FOUNDRYMEN CONFERENCE
Humans - Valuable Resource for Foundry Industry Development

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Natalija Dolić, Zdenka Zovko Brodarac, Sandra Brajčinović

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PREFACE

Knowledge is becoming an increasingly important resource for economic development. The Republic of Croatia is facing the challenges of the world economy, with the aim to meet certain requirements in shaping the education system. Ensuring the quality assurance of the education system is just one of the requirements set up as a continuous mission of University of Zagreb Faculty of Metallurgy and other co-organizers from the high-education. As the level of education of the population affects the progress of the economy, it is extremely important for the Republic of Croatia to increase the ratio of highly educated persons. In recent years, the ratio of the highly educated population of the Republic of Croatia has been growing, but in comparison with Europe, Croatia is still lagging behind. In order to increase the share of highly educated persons, it is necessary to invest in the quality of education, both in higher education and in secondary and primary education. This would increase awareness of the importance of education, which would ultimately result in an increase in the ratio of highly educated and competent professionals.

Metal industry as a base branch represents an important factor contributing to the economic potential of each country. Current market development as well as technical and economic objective, the production of high-quality, low-cost and environmentally friendly casting, requires application of recent and advanced materials, as well as production technologies, followed and supported by understanding of production process. The metal industry has been recognized as a "driving subdivision" of economy development.

Until the recession and deepening of the economic crisis in Croatia, companies operated stably, focused on streamlining production, investing in technology and employee's education, increasing product quality and productivity, developing innovation and fighting for the market. The recession and economic crisis have slowed the strengthening of this economic activity. In order to overcome and mitigate the negative results caused by falling orders and reduced production, companies have developed new production programs and sought new customers and markets in order to maintain good positions within their market niches. Taking into account the growing need of large (global) producers for small series products, it is assumed that it will build a network of suppliers in which Croatian producers can be included. Small quantities are sufficient to employ their production capacities, and with a skilled workforce and new market opportunities, the growth of existing companies is expected, as well as the establishment of new ones. By investing in modern equipment and production certification, metal producers indicate a desire for growth. The main features of Croatian industry are stable product quality and reliability in accordance with EU standards, while on the other hand it is important to invest in available professional workforce, targeted support of scientific institutions, good production infrastructure with emphasis on modern technologies and transport links to the world.

Despite the recognizability and importance of the profession, the profession is underestimated by the amount of the average net monthly salary per employee in legal entities. The gross value added of the product is also indicative. Since the Croatian market is too small for significant production growth, companies in the observed activity primarily direct their production capacities to EU countries, which also means increasing the level of productivity of assets and labor. Competitiveness can be based exclusively on modern technology, efficient production processes but also on a highly skilled workforce. All this requires investment in infrastructure and educational study programs that should strive to acquire primarily practical knowledge and skills with an emphasis on the development and application of modern materials and technologies, in order to change this status of the Republic of Croatia.

Therefore, the motto of the ***19th International Foundrymen Conference*** is focused to the **HUMANS** as a **valuable resource for foundry industry development**. Human resources have an unavoidable role in scientific, technological and practical aspects concerning research, development and application of casting technology with the common perspective – increase of competitiveness.

Special attention will be focused towards the competitiveness ability of foundries, improvement of materials features and casting technologies, environmental protection as well as subjects connected to the application of castings.
During this Conference 49 papers will be presented in hybrid mode (online and in situ) due to pandemia of COVID-19 virus. In this Conference scientists from 14 countries (Australia, Austria, Bosnia and Herzegovina, Croatia, Czech Republic, India, Kosovo, Poland, Romania, Spain, Serbia, Slovenia, Slovakia, United States of America) recognized the importance to be a part of this scientific event. Book of Abstracts of the 19^{th} International Foundrymen Conference includes summaries of the papers. The Proceedings book consists of papers *in extenso* published in electronic format (USB). Full length papers have undergone the international review procedure, done by eminent experts from corresponding fields, but have not undergone linguistic proof reading. Sequence of papers in Proceedings book has been done by category of papers in following order: plenary lectures, invited lectures, oral and poster presentation, and inside the category alphabetically by the first author's surname.
Within the Conference Student section is organized. This is an opportunity for industry to meet and recruit human resources as a main potential for business development. Coexistence of material science and sustainable technology in economic growth represent a knowledge transfer between small and medium enterprises' (SMEs´), industry and higher education institutions. Higher education at the Faculty of Metallurgy (HEI), conceived through the program and the learning outcomes, is based, inter alia, on promoting students' scientific and research work on applied topics, enabling ambitious and creative young people to become independent problem solvers, developing and supporting their curiosity, analytics and communication: **Graduates like the labour market needs!**
This occasion represents an opportunity to discuss and increase the mutual collaboration between HEIs' and industry with the aim of information exchange related to advanced experience in foundry processes and technologies, gaining the new experience in presentation and / or teaching methods and techniques within lifelong learning process.

The organizers of the Conference would like to thank all participants, reviewers, sponsors, auspices, media coverage and all those who have contributed to this Conference in any way.

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IMPACT OF MOULD POWDER ON PHYSICOCHEMICAL PROPERTIES OF SLAG IN THE CONTINUOUS CASTING PROCESS

Vaso Manojlović[1*], Željko Kamberović[1], Miroslav Sokić[2], Branislav Marković[2], Milorad Gavrilovski[3], Slobodan Radosavljević[2]

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Poster presentation
Original scientific paper

Abstract

Mould powder is essential for the reliable operation of the continuous casting system and the quality of the cast steel. The very responsible roles of mould powder are fulfilled by selecting combinations of components that affect physicochemical properties of the resulting liquid slag, which lubricate the walls among the crystallizer and slab. The contribution of mould powder refers to the range of melting temperature and speed and the viscosity of glassy or crystalline slag and formation temperature. These connections are the research subject in this paper, emphasizing the functional dependence of viscosity and liquidus temperature of mould powder with its material composition.
This research investigates the impact of basicity, alkali oxides (Na_2O and K_2O), and carbon-free content on viscosity and liquidus temperature of mould powder in the continuous casting process. The liquidus temperature of mould powder was obtained empirically after a year of experimental examination, and viscosity was determined using several models. Based on experimental investigation, we show empirical parameters for equitation of liquidus temperature of mould powder. Also, using established equations, we presented isolines for viscosity and liquidus temperature with experimental parameters.

Keywords: *casting powder, continuous casting, viscosity, liquidus temperature*

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INTRODUCTION

Mould powder is a synthetic product vital for a successful continuous casting process, minimizing defects and process problems. The basic functions of mould powder are:
- Protection of liquid steel from oxidation or nitration by forming liquid slag pool;
- Thermal insulation of liquid steel, preventing freezing of the steel meniscus;

- Formation of slag that lubricates the walls of the crystallizer and slab;
- Ensure even heat dissipation from the slab to the walls of the crystallizer;
- Dissolve inclusions and gas bubbles from the liquid steel;
- Control melting speed through lubrication of the formed steel shell and control of heat transfer;
- Provide formation of glassy or crystalline slag;
- Reduce scale formation [1-9].

Numerous parameters influence the properties of the mould powder, so optimization of its composition is based on empirical rules and plant data. Such parameters are chemical, mineral, granulometric composition, the surface-to-volume ratio of particles, and thermal conductivity. Main powder components are mineral components (oxides and fluorides) and carbon particles. The mineral component will form the mould slag and slag film, while carbon particles control the melting rate of the powder, meeting the requirements of liquid slag. Viscosities of mould powder and formed slag influence many parameters, such as powder consumption, brake (solidification) temperature, slag entrapment, lubrication supplied to the mould, and fraction crystal in the slag film (the ability of slag to dissolve inclusions). The slag viscosity increases with network forming components (e.g., SiO_2 and Al_2O_3) and decreases by introducing network braking oxides (e.g., CaO) or fluxes (e.g., Na_2O, K_2O, and CaF_2) [1-9].

This research investigates the impact of basicity, alkali oxides (Na_2O and K_2O), and carbon-free content on viscosity and liquidus temperature of mould powder in a continuous casting process. The liquidus temperature of mould powder was obtained empirically after a year of experimental examination, and viscosity was determined using several models. As a result of this paper, we show a method for predicting different parameters, and we obtain novel equations within the proposed boundaries of the powder composition. Based on experimental investigation, we get empirical parameters for equitation of liquidus temperature of mould powder.

MATERIALS AND METHODS

The experiments are done and verified in industrial conditions in continuous steel casting local plant for over one year. The mould geometry is designed for continuous casting of the carbon (0.06-0.20%C) steel slabs.

Tables 1 show the matrix of the experiment for pseudo components (relative contents) and actual values of examined components: X_1 - (CaO/SiO_2); X_2 - (Na_2O+K_2O); X_3 – Carbon-free, in mas.%. The method of simplex lattice plan, lattice type {3,2}, for the second-degree model, for three - component systems was used to perform the planned experiment. Following the chosen model, the number of experimental points there were seven, including a control point (point 7) for checking the adequacy of the obtained mathematical models (Figure 1).The chemical composition of mould powder is shown in Table 2; the amount of Fe_2O_3 was constant to avoid its impact on observed models.

The coefficients of the regression equation were determined based on the general, canonical form of polynomials of the second degree for three-component systems, in the coordinates of the pseudo components, according to equation [3]:

$$y = \beta_1 z_1 + \beta_2 z_2 + \beta_3 z_3 + \beta_{12} z_1 z_2 + \beta_{13} z_1 z_3 + \beta_{23} z_2 z_3 \quad (1)$$

Where *y* is optimization parameter; β_i, β_{ij} are regression equation coefficients; z_i are pseudo components. The objectives (y_i) of the research are viscosity and liquidus temperature of mould powder. The viscosity was calculated using *Riboud*, *Lida*, and *K. Mills* models [2, 8, 9]. Liquidus temperatures were obtained experimentally in plant conditions using a thermo-microscope (E. Leitz Wetzlar, max. temperature 1450 °C, with a constant heat rate of 10 °C/min).

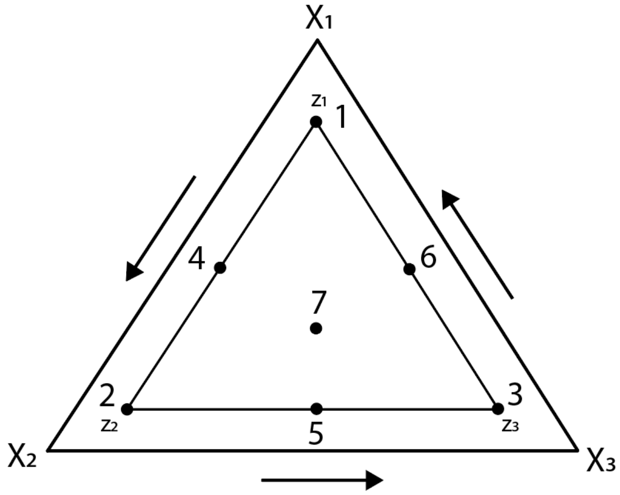

Figure 1. Experimental planning area and position of experimental points

Table 1. Matrix of the experiment for pseudo and examined components

Point of experiment	Pseudo components			The actual value of studied components		
	Z_1	Z_2	Z_3	X_1	X_2	X_3
1	1	0	0	1.2	6.5	7.5
2	0	1	0	0.7	9	7.5
3	0	0	1	0.7	6.5	10
4	0.5	0.5	0	0.95	7.75	7.5
5	0	0.5	0.5	0.7	7.75	8.75
6	0.5	0	0.5	0.95	6.5	8.75
7	0.33	0.33	0.33	0.86	7.32	8.32

Table 2. Chemical composition of mould powder, mas.%

Point of experiment	SiO_2	CaO	Al_2O_3	CaF_2	Na_2O	K_2O	Fe_2O_3	CO_2	C-free
1	22.23	26.78	7.00	5.61	6.04	0.46	2.63	21.76	7.5
2	28.01	19.72	5.00	6.71	5.72	3.28	2.63	21.43	7.5
3	28.16	19.82	5.00	6.68	6.20	0.30	2.63	21.21	10
4	24.78	23.55	4.33	5.50	5.01	2.74	2.63	23.96	7.5
5	28.1	19.79	5.00	6.75	5.00	2.75	2.63	21.23	8.75
6	24.86	23.62	7.09	6.34	5.88	0.62	2.63	20.21	8.75
7	25.94	22.33	4.82	4.93	5.85	1.83	2.63	22.43	8.325

Phase compositions of the mould powder was determined using XRD (PHILIPS PW-1710) with a graphite monochromator, using Cu-Kα radiation. The sample 7, in Table 2, was used for XDR characterization. The granulometric composition of sample 7 was (in mm): -0,06 = 74 mas. %; -0.09 +0.06 = 11 mas. %; -0.2 +0.09 = 12 mas. %; -0.5 +0.2 mas. %; and +0.5 =1 mas.%.

RESULTS AND DISCUSSION

The XRD analysis of the mould powder before melting showed that the basic components of the powder are: cuspidine, wollastonite, CaF_2, $CaCo_3$, Na_2CO_3.
Water will be removed above 100 °C, crystalline water and hydroxides at about 450 °C, carbon combust above 500 °C, and dissociation of carbonates with releasing of CO_2, above 650 °C.

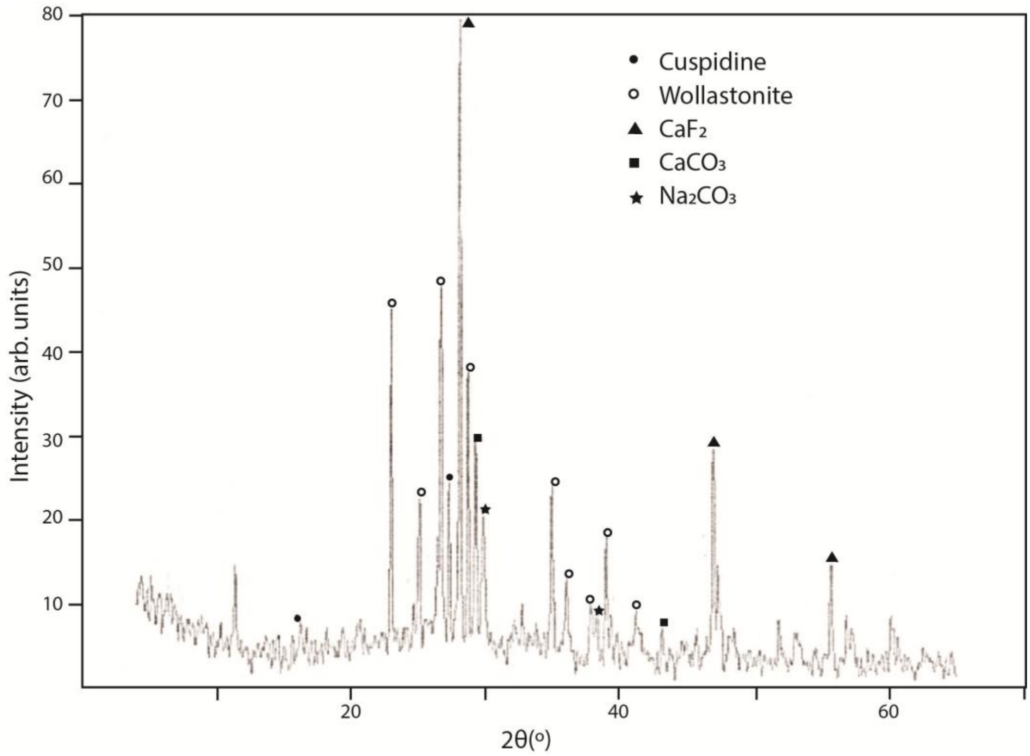

Figure 2. XRD analysis of the sample at point 7 (Table2)

The results of determining the values of regression equation coefficients for η and T_{liq} are given in equations 2 and 3.Table 3 shows calculated and actual values of liquidus temperature of mould powder for a given set of experiments. Since the *Lida* model corresponds best to the experimental data, we used this model to calculate the regression equation coefficients.

$$\eta = 1.679z_1 + 2.559z_2 + 3.484z_3 - 1.605z_1z_2 - 0.205z_1z_3 + 0.289z_2z_3 \quad (2)$$

$$T_{liq} = 1210.3z_1 + 1353.5z_2 + 1388.1z_3 + 0.001935z_1z_2 + 0.01476z_1z_3 + 57.90z_2z_3 \quad (3)$$

Table 3. Comparative values of experimental data and calculated values

Point	Viscosity, η [dPas]				Liquidus temperature, T_{liq} [°C]	
	Riboud	Lida	Mills	Calc.	Experiments	Calc.
1	1.79	1.68	2.04	1.68	1210	1210
2	3.02	2.56	8.65	2.56	1353	1353
3	3.85	3.48	12.04	3.48	1388	1388
4	1.98	1.72	2.27	1.72	1282	1282
5	3.53	3.09	11.06	3.09	1385	1385
6	2.82	2.53	5.52	2.53	1299	1299
7	2.32	2.38	3.56	2.38	1310	1310

Figures 3 and 4 show isolines at different basicity for liquidus temperature and viscosity of mould powder using equations 2 and 3, respectively.

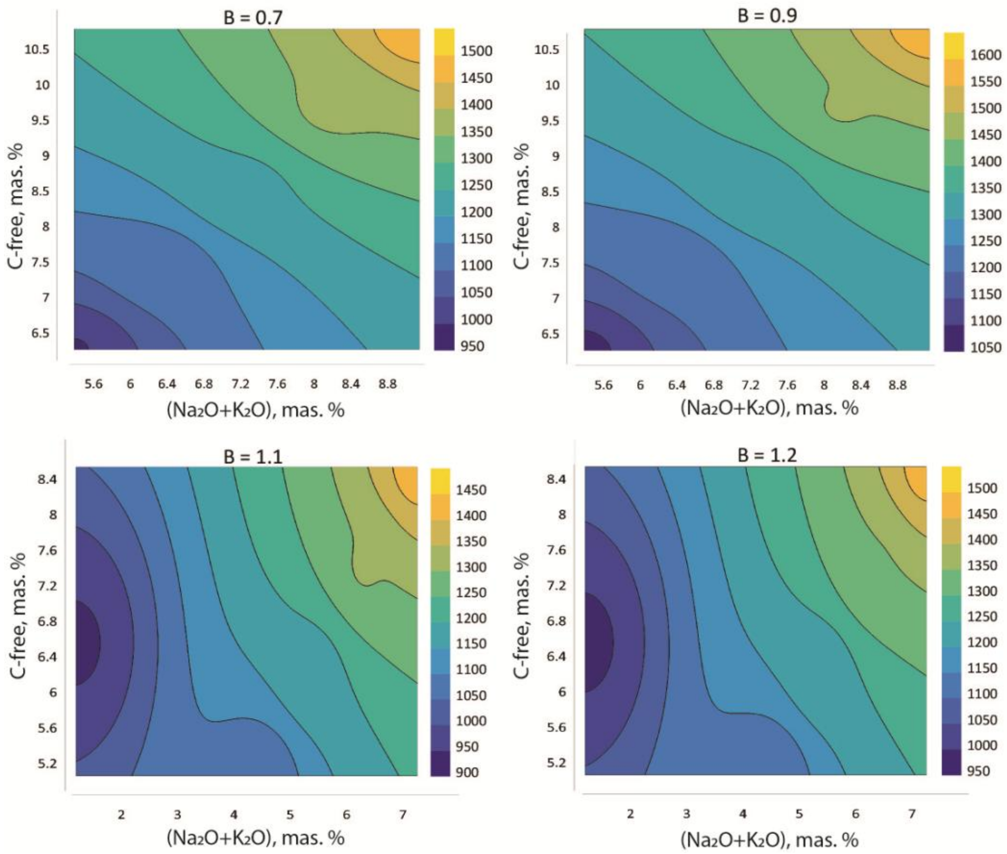

Figure 3. Liquidus temperature profiles (in *°C*)

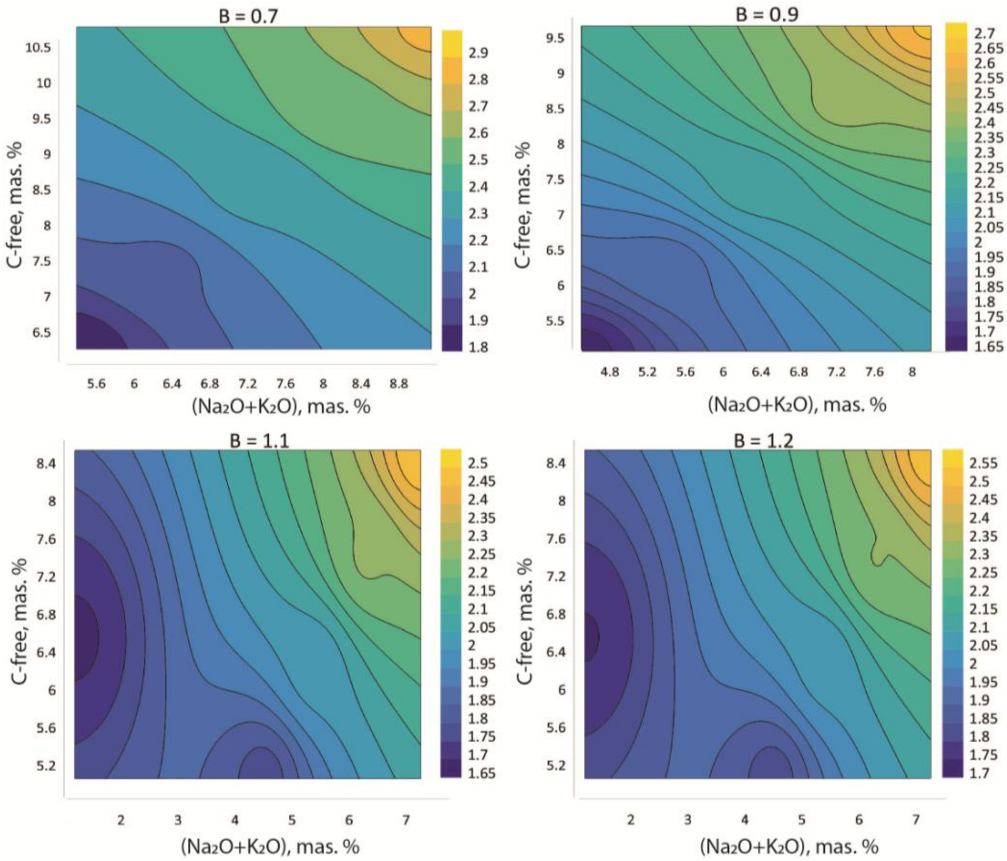

Figure 4. Viscosity profiles (in *dPas*)

Figure 4 shows appears of two local minimums, at middle of ranges of C-free and (Na_2O+K_2O) content, and higher values of basicity. One could note that effect of Na_2O and K_2O is synergetic, as we observed the sum of those components; however, the effect of Na_2O is much higher than K_2O, as it is shown in literature [1, 2]. The content of Al_2O_3 was in the range in the 4.3 to 8 mas. %, we did not examine its impact. Though, it would be very interesting to find correlation of this component, due to its dual and complex nature: it is capable to from or break oxygen networks.

CONCLUSIONS

In the presented work we presented method for getting regression equation coefficients for viscosity – η, and liquidus temperature – T_{liq},of mould powder. The obtained equation could be used for a given range of chemical composition of mould powder. Also, using obtained equations we show isolines for viscosity and liquidus temperature with experimental parameters. Those results are very important for industrial application, due to influence of viscosity and liquidus temperature on many parameters, such as melting speed, consumption of powder (increases with increasing viscosity), slag entrapment, lubrication supplied to the mould, and fraction crystal in the slag film (the ability of slag to dissolve inclusions).

Acknowledgments

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REFERENCES

[1] K. C. Mills, C. A. Däcker, The casting powders book, Chapter 9, Springer, Switzerland, 2017.

[2] K. C. Mills, S. Karagadde, P. D. Lee, L. Yuan, F. Shahbazian, Calculation of physical properties for use in models of continuous casting process-part 1: mould slags, ISIJ international, 56(2016)2, pp. 264-273.

[3] D. Gavrilovski, M. Gavrilovski, Determination of the chemical stability of glass-ceramic enamels, Proceedings of XLVI ETRAN Conference, (Ninoslav Stojadinović), The Society for Electronic, Telecommunications, Computers, Automation and Nuclear Engineering, Vol. IV, June 4-7, 2002, Banja Vrućica – Teslić, Serbia, pp. 250-252.

[4] B. Arh, F. Tehovnik, F. Vode, Change of mould flux properties during continuous casting of ferritic stainless steel, Metalurgija, 56(2017)1-2, pp. 40-42.

[5] A. Kamaraj, N. Haldar, P. Murugaiyan, S. Misra, High-Temperature simulation of continuous casting mould phenomena, Transactions of the Indian Institute of Metals, 73(2020)8, pp. 1-7.

[6] E. Brandaleze, G. Di Gresia, L. Santini, A. Martín, E. Benavidez, Chapter 7, Mould fluxes in the steel continuous casting process, Science and technology of casting processes, IntechOpen, BoD–Books on Demand, 2012.

[7] J. A. Kromhout, R. C. Schimmel, Understanding mould powders for high-speed casting, Ironmaking & Steelmaking, 45(2018)3,pp. 249-256.

[8] P. V. Riboud, Y. Roux, L. D. Lucas, H. Gaye, Improvement of continuous casting powders, Fachber, Huttenprax Metallweiterverarb, 19(1981), p. 859.

[9] I. Takamichi, H. Sakai, Y.Kita, K. Murakami, Equation for estimating viscosities of industrial mold fluxes, High Temperature Materials and Processes, 19(2000)3-4, pp. 153-164.