Use of Natural Materials for the Modelling of Steel Refinery Slags

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***Abstract*-The submitted paper deals with experimental study of simulated refining systems. It focuses on two methods of melting temperature measurement by using the high-temperature microscope and the thermocouple in Marsh furnace. Temperature represents one of the most important physico– chemical properties of metallurgical slag systems. The melting interval is measured by using high temperature microscope while melting temperature is measured by using the thermocouple in Marsh furnace. It was found that both methods are suitable for the measurement of the slag systems melting temperature up to 1450°C and can give reliable results. The obtained results were confronted with theoretical knowledge. For experiment, slag systems similar to the Reactol 400/2 used as a refined tundish slag in Podbrezová Steel Plant were employed. Systems were done by combining natural materials with pure oxides.**

Keywords-Continuous Casting; Steel Refinery Slag; Slag Properties; Melting Temperature; High–temperature Microscope

I. INTRODUCTION

As to continuous casting of steel, it is important to know properties for solidification of steel (such as melting point, viscosity, density, thermal conduction and solid state phase transformation temperatures) as well as properties that are relevant to a proper functioning of the mold slag. The efficiency of steel continuous casting is determinated by technological factors and by the applicaiton of the slag powdery mixtures for steel protection in crystallizer tanks of the continuous casting devices [1], [2].

The slags form a multicomponent system, which has a direct contact with melt. The composition of slag (composed mainly from oxides, alkaline and alkaline – earth), its chemical properties, melting temperature, viscosity, surface tension and its other properties influence the quality of produced metal, the intensity of production and the stability of running equipment. The chemical composition and the temperature strongly influence their structure. At present, scientists lack comprehensive sets of information describing heterogeneous processes of slags at high temperatures, and obtainment of data is difficult. [3], [4] – [9].

During the process of continuous casting, slags can be divided into:

a) cover and refined slags, which tend to be used in tundish, and

b) slags arising from mould fluxes in crystallizer.

In the process of continuous casting, the slags carry out the following important technological functions**:**

a) Protection of the metal against contact with the surrounding environment; thermal insulation;

b) Absorption of inclusions floated out during the casting;

c) Stabilization of the process of casting;

d) Show minimal corrosive effects [6], [10], [11].

The temperature is one of the major characteristics of the technological process of melting. The energetic or thermodynamic state of the material depends upon the heat-mass and physico-chemical transformations taking place during the melting [12], [13].

It is possible to determine the melting temperature of oxidic system in several ways. However, any temperature determination requires a rigorous observation of any given sample [14], [15]. One of the methods of measuring the melting temperature consists of measurement with the use of a thermocouple. This method has become very popular in metallurgy and serves as an accurate source of information [12]. Several authors employ this method [16] – [18]. Another commonly used method of measuring the temperature of melting is the high temperature analysis. It is a relatively simple method that requires small claim on the sample weight, but it remains rather time-consuming [19]–[21].

II. MATERIAL AND EXPERIMENTAL METHODS

Experiments were designed to study the melting temperature of modeled slag systems. Systems were devised by combining natural materials with pure oxides. The new system chemical composition calculations were done by program HSC 5.1, whose composition is close to the composition of REACTOL 400/2 slag used as a refining slag in the basin of Podbrezová Steel Plant. The source material for both simulated systems was dolomite limestone, which was modified by dissociation on dolomite lime. To the dolomite lime were added 35 % Al_2O_3 and SiO_2 4 % (the first slag system) and 33 % Al_2O_3 and 10% clay lime (the second slag system). Chemical composition of REACTOL 400/2 as well as the chemical composition of the first and second system is shown in Table 1.

TABLE I CHEMICAL COMPOSITION OF REACTOL400/2 AND TWO MODELED SLAG SYSTEMS

Label samples	Content [weight %]					
	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Sum
REACTOL 400/2*	48,8	18,3	6,70	24,4	1,8	100
1. Modeled slag system (RS-1)	45,69	22,04	5,58	25,77	0,62	99,67
2. Modeled slag system (RS-2)	45,53	21,70	6,65	24,86	1,03	99,77

*content of components for converting CO_2-free (15 %)

Jung et al [22] confirm that the CaO-MgO-Al_2O_3 systems are fundamental to the understanding of metallurgical slags, refractories, ceramic materials, and geological phenomena.

According to the ternary diagram CaO - MgO - Al_2O_3 at temperature 1400°C, the composition created from three major elements of modeled samples were used. (Fig. 1 – Melting area indicated by a dashed line for both modeled systems). This composition has not been used in practice because other additives (Fe_20_3, SiO_2) are present in the sample of modeled slag systems and have influence on the melting temperature. Therefore it was necessary to determine the melting temperature of system including 5 components.

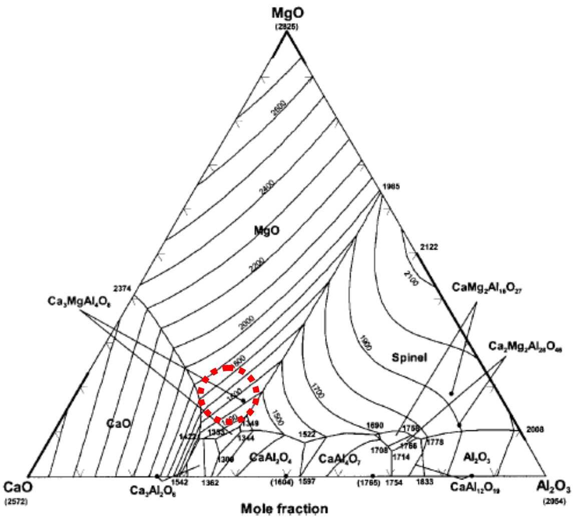

Fig. 1 Ternary diagram of CaO – MgO – Al_2O_3 system [22]

The experiment was actualized by using the high-temperature LEITZ Wetzlar microscope, which is possible to apply to the temperature 1550 °C. The temperature of the sample is registered by digital thermometer and displayed on the screen below the sample. Melting range at this methodology is determined according to ISO 540:1995. The temperature ranges from the value when a melt appears for the first time (for instance, drops on the sample surface, melt meniscus on the contact pad – a sample) to the temperature when the sample reaches a spherical shape (outdoor dome), the surface of which is without ridges. Principle of temperatures recorded consists in the fact that microscopically magnified image of the sample size of 3 × 3 × 3 mm (sample lies in electronic oven) is projected into a matrix that is observed and photographed. The temperature is read from the screen, which is reflected in the temperature scale of the galvanometer.

III. RESULTS AND DISCUSSION

The main aim of the experiment was to determine the melting temperature as a very important characteristic of slag. A microscope with high range temperature to determine the melting interval of modeled systems was used. The temperature was studied at two modeled systems (RS – 1 and RS – 2) and also at sample of Reactol. Shape of the sample1 and 2.modeled slags system at different temperatures is shown in Fig. 2 and 3.

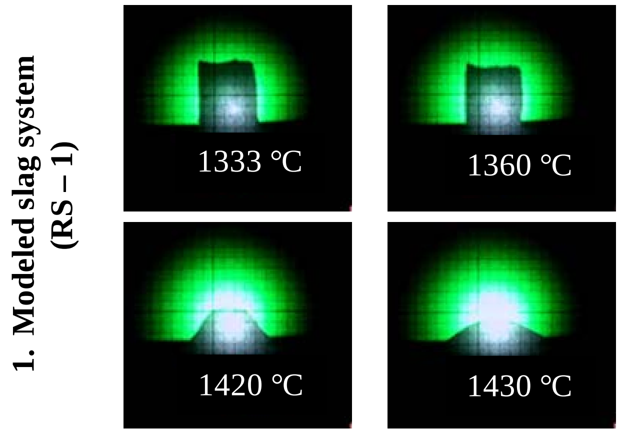

Fig. 2 Temperature course of the 1. modeled slags system using high temperature microscope

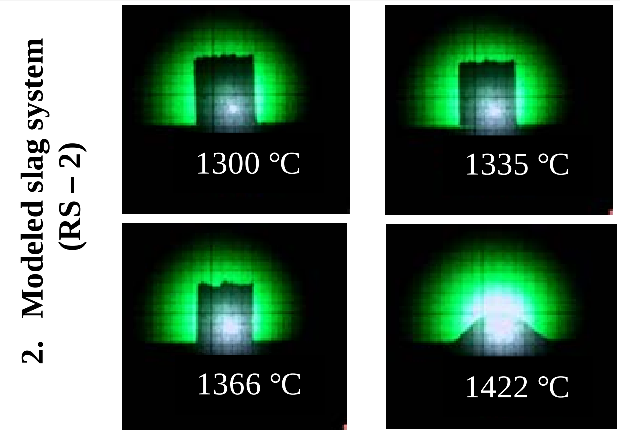

Fig. 3 Temperature course of the 2. modeled slags system using high temperature microscope

The sample of the first system was studied in the range from 15 °C to 1452 °C. At temperature 1333 °C there was no noticeable change in shape and volume of the sample. Melting of the sample leads to the fact that the sample can acquire a barrel shape, and between the sample and the pad, meniscus or edges can be formed around the sample. In our case, the creation of the first barrel is visible at 1360 °C. This temperature (solidus temperature) can be regarded as the beginning of the sample melting. According to the norm DIN 5173, the melting interval ends when reaching a hemispherical shape of the original cube, in which case the temperature is 1420 °C (temperature of liquidus).

Even in that sample with the temperature 1330°C there was no noticeable change in shape and volume of the sample. The first visible changes were observed at 1335°C when sample was sintering, and the meniscus was created. At temperature 1366°C there is a visible creation of the first barrel. The interval of melting is estimated from 1366°C to 1422°C. In this interval, there was a change in sample shape on hemispherical. After reaching the liquidus temperature (the melting interval end) 1422°C, the melt was homogeneous, and above that temperature the sample flowed.

Fig. 4 shows the course of melting and thermal gradient of the Reactol 400/2 and the intended its melting rate.

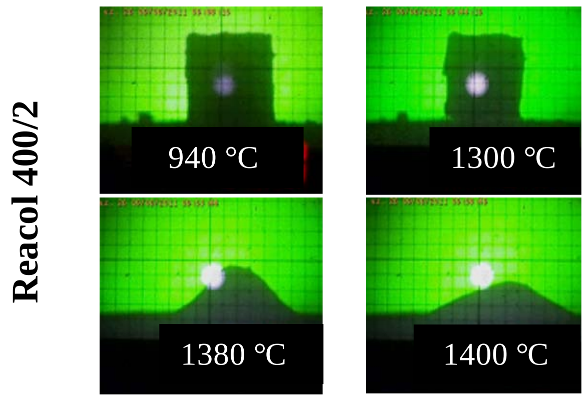

Fig. 4 Temperature course of the Reactol 400/2 using high temperature microscope

The sample of the Reactol 400/2 was studied in the range from 8 °C to 1450 °C. The measured results show that at temperature 940 °C there was no noticeable change in shape and volume of the sample. The first visible changes were observed at 940 °C, when it began to shrink slightly. Soft creation of barrel was recorded at 1280 ° C. The beginning of melting of the sample (solidus temperature) when the temperature is 1300 ° C, the sample has significantly changed its shape. Hemispherical shape of the original cube entered the sample at 1380 °C (temperature of liquidus). The interval of melting is estimated from 1300 °C to 1380 °C. Above that temperature of liquidus (1380 °C) the sample was flowed.

In Fig. 5 it shows a comparison of melting interval of RS – 1, RS – 2 and Reactol 400/2 using high – temperature microscope.

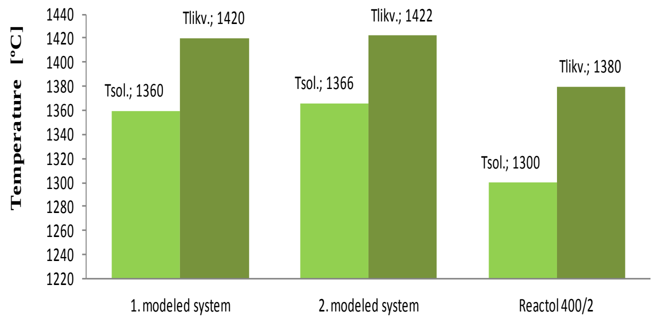

Fig. 5 Comparison of melting interval for the 1and 2 modeled slag system and Reactol 400/2 using high temperature microscope

To verify and possibly complement the experimental results, the method of measuring the melting of debris by using a thermocouple in Marsh furnace with working temperatures up to 1450 °C was used. The temperature measurement is performed by thermocouple, indication PtRh10 - Pt, which is attached to the transducer and transmits the voltage from the thermocouple temperature. The measurement principle is that the sample is placed into ceramic sample boat (on the base of Al_2O_3) in the middle of the furnace, hold 10 minutes at a temperature of about 1400 °C, and then is gradually ejected after 1 cm (8 - times), at which time temperatures are read.

Sample 1 and 2 modeled systems were performed with three measurements of melting temperatures and for the sample of Reactol 400/2 one measurement. The measurement principle of softening, melting and flowing temperature using thermocouple in Marsh furnace is shown in Fig. 6 for RS – 1, RS – 2 (Fig. 7) and Reactol 400/2 (Fig. 8). By Figs. 6,7,8 delete text box „length of analyzed zone" and give the text box " temperature" closer to the y axis

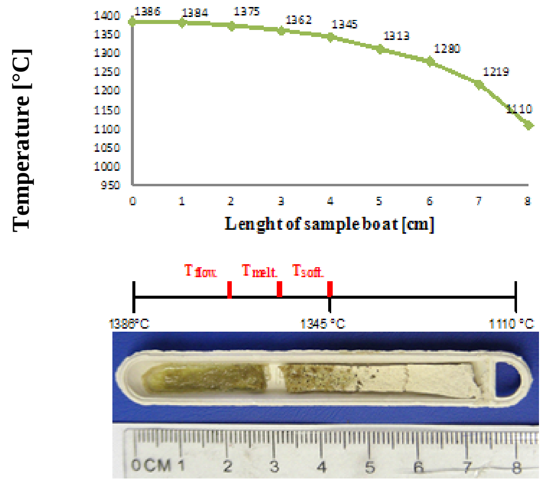

Fig. 6 Temperature course of the 1. modeled slags system using Marsh furnace

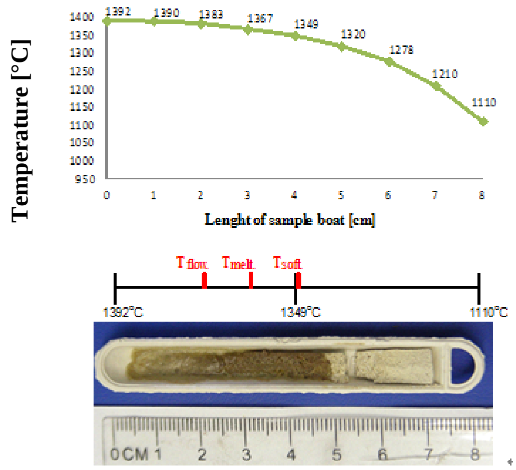

Fig. 7 Temperature course of the 2. modeled slags system using Marsh furnace

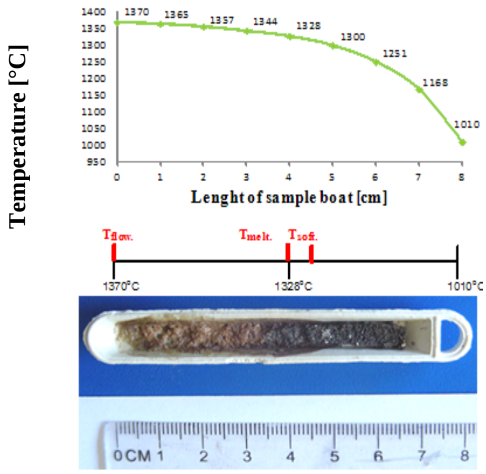

Fig. 8 Temperature course of the Reactol 400/2

The course of melting is visible in the first sample simulated system (Fig. 6) and can provide visual softening temperature, melting and flow. An interval of softening was defined from 1345 °C to 1362 °C, whereby softening temperature is 1345 °C. Melting temperature was determined on 1362 °C and the interval of melting is estimated from 1362 °C to 1375 °C. The flowing temperature was considered on 1375 °C and over which temperature the sample was fluent.

Fig. 7 shows the course of melting and thermal gradient of the second sample of slag system, the intended melting rate of the first modeled slag system and also the temperature running of the second modeled slag system.

On a sample of the second slag system it can visually determined the temperature of softening, melting and flow sample.

In that case, an interval of softening was defined from 1349 °C to 1367 °C, whereby softening temperature is 1349 °C. The melting temperature was determined on 1367 °C and the interval of melting is estimated from 1367 °C to 1383 °C. The flowing temperature was considered on 1383 °C and over that temperature the sample was fluent.

Fig. 7 shows the course of melting and thermal gradient of the Reactol 400/2.

In that case (Fig. 8), an interval of softening was defined from 1314 °C to 1328 °C, whereby softening temperature is 1314 °C. The melting temperature was determined on 1328 °C and the interval of melting is estimated from 1328 °C to 1383 °C. The flowing temperature was considered on 1370 °C.

Fig. 9 shows a comparison of the measured temperatures of the two modeled systems (RS-1 and RS-2) and Reactol 400/2 by using a thermocouple in the Marsh furnace.

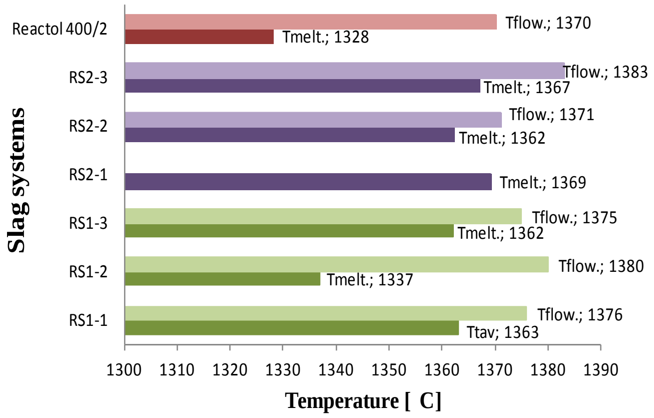

Fig. 9 Comparison of measured temperature for the 1 and 2 modeled slag system and Reactol 400/2 using Marsh furnace

During the measurement of melting temperature in the Marsh furnace, the sample did not melt. The reason is that the sample contained part of the hard fusible phase with higher melting temperature that causes the sample in the observed temperature range not melted.

Fig. 10 shows a comparison of the measured temperatures of the two modeled systems (RS-1 and RS-2) and Reactol 400/2 by using both methods of temperature measuring, a high temperature microscope and Marsh furnace.

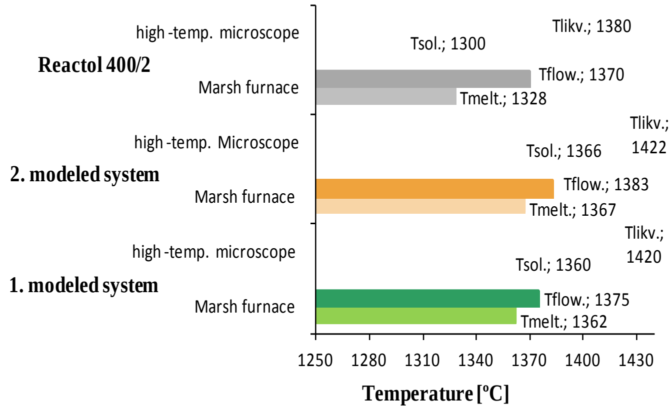

Fig. 10 Comparison of measured temperature for the 1 and 2 modeled slag system and Reactol 400/2 using high temperature microscope

The aim of the melting was to achieve a melting temperature at which the samples were completely melted. With the obtained results we wanted to approach to the temperature values of the REACTOL 400/2 given by the manufacturer. An accuracy of our results is confirmed, because flow temperature set value indicated by the manufacturer for REACTOL 400/2 is 1430 ° C.

IV. CONCLUSIONS

The utilization of raw materials in various industrial regions mainly depends on the knowledge of their properties. The results of using dolomite limestone as a source material for simulation of slag systems show that this material is suitable for melting processes. Experimental results achieved can be formulated as follows:

Determined melting interval by high temperature microscope is about 47 °C higher for the first slag system, and for the second slag system is about 40 °C.

Determined flow temperature indicated by producer for REACTOL 400/2 is up to 1430 °C because a sample of the first system was determined on 1375 °C and the second system on 1383 °C (results from Marsh furnace).

The melting ranges of used samples measured in Marsh furnace lie in melting interval determined by high temperature microscope.

Finally, it is possible to conclude that, dolomite limestone perspective mineral stock can be used in process of continuous casting based on the obtained result.

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