ISSN 0543-5846
METABK 50(3) 209-211 (2011)
UDC – UDK 669.18:666.88:532.6:669.187=111

SURFACE TENSION OF EXPANDED SLAG FROM STEEL MANUFACTURING IN ELECTRICAL FURNACE

Received – Prispjelo: 2010-06-21
Accepted – Prihvaćeno: 2010-11-10
Professional Paper – Strukovni rad

In the article a research on the surface tension of slag was conducted from the process of obtaining steel in the electric furnace. Melting in the graphite melting crucible caused the slag to foam. The measurement of the surface tension is being conducted with method of rejection. They make the measurement of maximum power needed for the liquid to reject the working element of the apparatus from the surface. The research was conducted in the temperature of 1 673 – 1 723 K. The results of the measurements allowed to determine the surface tension of slag, which in the analysed scope of the temperature is being changed from 454 to 345 $mN \cdot m^{-1}$.

Key words: steel, slag, surface tension, electric furnace

Površinska napetost troske raširene po čeliku proizvedenom u elektropeći. U radu je provedeno istraživanje površinske napetosti troske u procesu proizvodnje čelika u elektropeći. Taljenje u grafitnom loncu uvjetuje da troska pjeni. Mjerenje površinske napetosti provedeno je metodom izbacivanja. Metodu omogućuje mjerenje maksimalne snage potrebne da se iz taline izbaci radni element uređaja s površine. Istraživanje je provedeno u rasponu temperatura 1 673–1 723 K. Rezultati mjerenja omogućuju određivanje površinske napetosti troske koja se u analiziranom rasponu temperature mijenja od 454 do 345 mN/m.

Ključne riječi: čelik, troska, površinska napetost, elektropeć

INTRODUCTION

Surface tension of slag exerts a considerable impact on the kinetics of the reactions taking place at the boundaries of the liquid slag – liquid metal phases, when a gaseous phase is released, for various kinds of metal refining processes conducted using synthetic slags, the corrosion reaction at the furnace or ladle lining under the impact of slags, etc. [1].

However, in the scope of the said processes, the subject of practical interest of a metallurgist or a founder is not only the mere surface tension but also the interfacial tension at the phase boundaries between e.g. slag and inclusions, slag and metal, slag and lining, liquid alloy and moulding sand, etc. [1].

The area of the interface and the phenomena taking place on it are crucial for numerous high and low temperature manufacturing processes [2].

The speed of a heterogeneous process taking place at the interface boundary is directly proportional to the interface area, therefore the latest methods of manufacturing and refining of metals assume being performed in dynamic metallurgical reactors. The quality parameter of the process is equally important as the surface area. The phenomena occurring on the interface may be decisive for the speed of the entire process [2]. However, depending on the relevant conditions, they can increase or decrease the speed until the processes is completely stopped.

Tension of liquid metals is higher than that of liquids, and its value falls within a wide range from 400 $mN \cdot m^{-1}$ to 1 900 $mN \cdot m^{-1}$ [2 - 6]. Surface tension of liquid slag and its solutions is lower than that of liquid metals and reaches the value of 100 $mN \cdot m^{-1}$ to 500 $mN \cdot m^{-1}$ [7 - 12]. For most organic liquids, the tension value falls within the range from 20 $mN \cdot m^{-1}$ to 45 $mN \cdot m^{-1}$ [3].

Surface tension of pure metals depends on temperature and rises as their melting points increases. Tension of liquids also rises together with the value of the forces acting between the liquid's structural components as well as with the number of structural particles which may create non-saturated field of forces in the superficial layer of liquids [2, 3].

The foaming phenomenon is quite common in the industrial practice. The liquids subject to it include the slags from the steel manufacture in electrical furnace. One of the most crucial aspects of the phenomenon of creating and consolidating foams is the contribution of surfactants [8]. Substances decreasing the surface tension facilitate foaming of liquids and also exert a significant impact on the durability of foam by being absorbed in an oriented manner on the surface of bubbles.

J. Łabaj, G. Siwiec, B. Oleksiak, Department of Metallurgy, Silesian Technical University, Katowice, Poland

The phenomenon of forming bubbles as well as the question of how long they can last have been the subjects of numerous studies [4, 5]. What is definitely more difficult is to measure the physical and chemical properties of foaming slags. There are very few methods which can be applied for the analytical purposes, and an additional limitation is the choice of appropriate materials for the working elements of the testing apparatus [1, 6 - 9, 11].

ANALYTICAL PART

The study consisted in measuring surface tension of expanded liquid slag from steel manufacture in an electrical furnace. The tests were conducted by measuring the force required to separate the measuring piece from the liquid surface. The said method enables determination of surface tension γ using the following formula [11]:

$$\gamma = \frac{(W - Wp) \cdot g}{2 \cdot (x + y)} \tag{1}$$

where:
W – force required to separate a plate from the liquid surface,
W_{plate} – plate weight,
g – gravitational acceleration,
γ – surface tension,
x – plate width,
y – plate thickness.

TEST MATERIAL

The material used for the sake of the tests was the slag from the steel manufacturing processes in an electrical arc furnace of the chemical composition provided in Table 1.

TESTING APPARATUS

The measuring station was built based on a Tamman furnace with precision temperature control (up to 1 973 K), an analytical balance and a mechanism of accurate and smooth vertical shift. The diagram and the general layout of the station have been provided in Figures 1 and 2.

Inside the furnace, a tube was installed to support a crucible to contain the test sample, enabling introduction of inert gas into the furnace's working section.

Table 1 **Chemical composition of the test slag.**

	CaO/SiO_2	0,72
Content / % wt.	FeO	25
	CaO	21,8
	SiO_2	30,5
	MgO	3,9
	Al_2O_3	4,4
	TiO_2	5
	K+Na	8

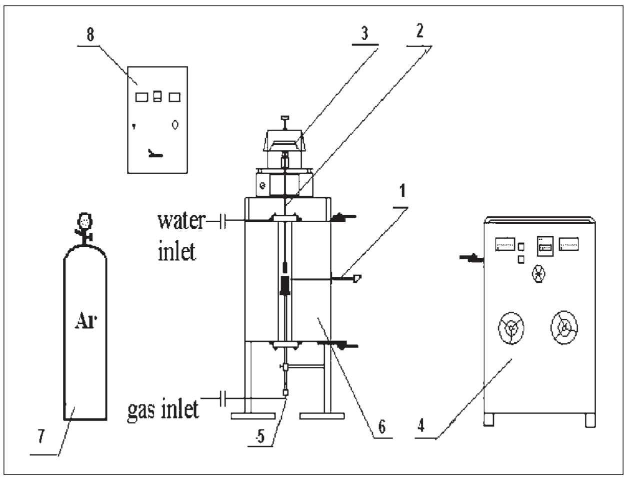

Figure 1 Diagram of the surface tension measuring station 1 – thermocouple, 2 – floating suspension, 3 – analytical balance, 4 – power cubicle, 5 – corundum tube, 6 – Tamman furnace, 7 – inert gas, 8 – furnace control cabinet.

Figure 2 View of the surface tension measuring station.

The process temperature was measured by means of a type Pt-Pt Rh 6 thermocouple installed directly at the crucible.

TEST METHOD

The crucible made of Al_2O_3 containing the sample was placed centrally on the support and introduced inside the furnace's working chamber. In order to secure the graphite components, inert gas (argon) was passed through the furnace chamber. Then the sample was heated to the appropriate temperature.

After the melting, in order to attain foaming, graphite was introduced into the slag. Next, on a tared balance, a float being a zirconium oxide plate was suspended. The heating system was thermally insulated in order to minimise the impact on those elements which influence the relevant measurements. The float suspended on the balance pan was immersed and lifted from the liquid slag while the balance readings were being recorded. The measurement results obtained were then used to deter-

Table 2 **Results of the liquid slag surface tension measurements**

Item	Surface tension / $mN\cdot m^{-1}$	Standard deviation
1,673	391,31	44,62
	490,5	
	480,69	
mean	454,17	
1,723	367,33	24,41
	311,74	
	358,61	
mean	345,89	

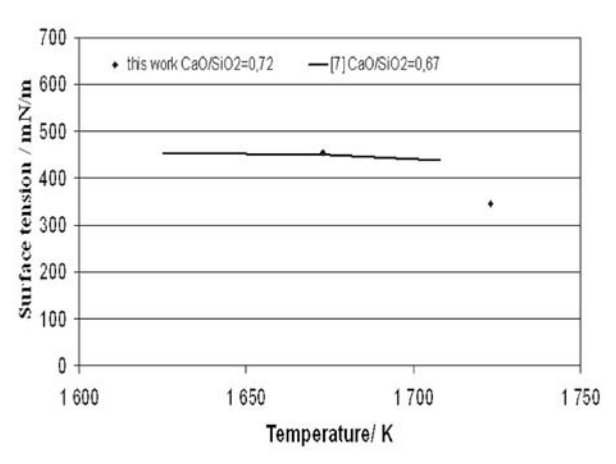

Figure 3 Change of the surface tension of expanded slag from the steel manufacturing process in electrical furnace.

mine the surface tension of the expanded slag based on formula (1). For each temperature, three measurements were conducted. The results obtained have been collated in Table 2 as well as presented in a graphical form in Figure 3.

CONCLUSIONS

The forecasts by 2 050 show that the EAF will be a dominant one in the technology of obtaining steeel.

Economy of the electric arc furnace technology is strongly dependent on the efficiency of electrical energy introduced into the metal bath. Slag foaming practice for carbon steel grades has been used for a long time, but still not for stainless steel. Production cost lowering is achieved by improving thermal efficiency and operation conditions by stabilizing of the arc activity. In consequence, the refractory and electrode consumption as well as the noise level are noticeably decreased.

All of these effects can be now achieved bduring the production of stainless steel.

Some important benefits can be obtained in the EAF through the foaming slag practice. Slag is not foamed only to protect the refractory bricks from the arc and to lower the electrodes consumption, but also to improve the heat transfer from the arc to the metallic bath, and to decrease the melting time. The reactions that generate gas bubbles are required for the process of slag foaming. The slag must have some physical and chemical characteristics to sustain the gas bubbles.

This is a very simple method and therefore is suitable for an application in case of liquids at high temperatures, thus for liquid metals [11, 12] and liquid slag [4, 8, 13-15]. One of more serious problems in this case is a proper selection of materials for the float together with suspension and for crucible. In case of measurements of slag density [4, 9] as material suitable for the float is platinum or other chemically resistant metal with sufficient high melting point.

The separation method applied proved applicable for the sake of measuring surface tension of foaming liquids. The surface tension determined (mean values) in the course of the tests conducted came to 454 $mN\cdot m^{-1}$ at the temperature of 1 673 K and 345 $mN\cdot m^{-1}$ at the temperature of 1 723 K. The surface tension results obtained under the study of the slag being examined are characterised by considerable impact of temperature on the values measured. The surface tension measurement results discussed in paper [7] for a system of oxides on the value of CaO/SiO_2=0,67 imply that the impact of temperature is very limited.

REFERENCES

[1] A. Staronka, M. Piekarska: Archiwum hutnictwa Book 1-2, 27 (1982), 1287.
[2] J. Botor: Podstawy inżynierii procesowej. Wyd. Pol. Śl. Gliwice (2002).
[3] A.W Adamsom.: Chemia fizyczna powierzchni, PWN, Warszawa (1963).
[4] R. Jiang, R.J. Fruehan.: Met. Trans. B 22B (1991), 481.
[5] I. Kimihisa, R.J. Fruehan: Met. Trans. B 20B (1989), 509.
[6] J. Łabaj, B. Sikora, A. Fornalczyk: Rudy Metale 4 (2005), 621.
[7] D. Skupien, D.R. Gaskell: Met. Trans. B., 31B (2000), 921.
[8] G.Siwiec, J. Botor: Rudy Metale 12 (2002), 342.
[9] J. Willner, J. Botor, G. Siwiec: Rudy Metale 6 (2007), 432.
[10] J. Łabaj, B. Sikora: Acta Metallurgica Slovaca 10 (2004), 187.
[11] A. Staronka, M. Piekarska: Archiwum hutnictwa Book 1, 23 (1978), 1123.
[12] J. Łabaj: Rudy i Metale 4 (2010), 548.

Note: P. Nowak is responsible for English language, Katowice, Poland.