APPLICATION OF OPTICAL BASICITY PARAMETER TO FOAMING OF SLAGS

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Metallurgical slags play an important role in the melting and refining of metals. Efforts are being made, by many researchers, to understand the factors influencing the properties of slags. Optical basicity is a chemical parameter which has been applied to glasses and slags, and, is a more comprehensive representation of slag composition than conventional basicity. Foaming is an important phenomenon in steelmaking, but limited information is available on the effect of slag composition on foaming. Optical basicity values, for different slags, were calculated from the chemical composition – following the approach of Duffy and co-workers. The calculated values were then applied to follow the trends in foaming, bath smelting and ladle slags. The results demonstrate the potential use of optical basicity in this area, but the trends could be investigated further with respect to structure and the ionic concentrations.

KEYWORDS: metallurgical slags, foaming, chemical composition, optical basicity

INTRODUCTION

Selection and performance of slags is very critical for many operations in melting, refining and casting of metals. Chemical properties of metallurgical slags such as chemical composition and basicity as well as physical properties such as fusion temperature, viscosity, foaming index have a strong influence on the performance of slags [1]. However, physical properties of slags need to be measured at elevated temperatures and often difficulties are encountered in the same. Hence, the need to predict properties of slags based on chemical composition and certain empirical relations. Optical basicity, a parameter based on the ionic nature of oxides, has been used for predicting the properties of glasses and slags. The present work is an attempt to track the variations in foaming behaviour of slags, as function of optical basicity. The approach has been used for studying the behaviour of three different types of slags used in ironmaking and steelmaking.

FOAMING

Foam is a system consisting of a concentrated dispersion of gas bubbles in a liquid. Foam properties depend primarily on chemical composition, interfacial characteristics, rheology, pressure and temperature. Foaming has been observed in metallurgical processes such as oxygen steelmaking, but has become a critical phenomenon in the newer process modifications. Experimental investigations, based on actual foam measurements and physical models have been reported in the literature [2]. Viscosity has been cited as an important influencing variable, but not much work has been done on the relation between chemical composition and foaming. This becomes significant as the experimental measurement of viscosity is a difficult proposition.

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CONCEPT OF OPTICAL BASICITY

Oxide slags used in melting and refining are considered ionic in nature and the behaviour of the slag is strongly influenced by the chemical composition, structure and nature of ions/ionic charges. Parameters such as basicity do not take into consideration the presence of many oxide species (other than lime and silica) and also the ionicity is itself a function of the chemical composition. The relation between the ionic structure and optical basicity for salts, glasses and slags as well as the significance of optical basicity in metallurgical processes has been described in the literature [3-7]. Procedures for calculation of optical basicity have been described, in detail, in the literature. Calcium Oxide is taken as the anchor point with an optical basicity value of 1 and different numerical values have been assigned to the other oxides. Therefore, the optical basicity value of a slag can be simply calculated from the chemical composition (expressed in equivalent fractions of ions) and the polarizing powers of different ions. The optical basicity ($\wedge$) of a slag is given by:

$\wedge = {}^{\wedge}{}_{1}X_{1} + \wedge 2X2 + \ldots\ldots$

where $\wedge_i$ is the optical basicity of the pure oxide i, and X_i is the equivalent fraction of oxide i.

PROBLEM FORMULATION AND APPROACH

Physical properties of slags – such as foaming index and viscosity have been experimentally measured by other researchers

Sl. No.	Type of Slag	Indicative Slag composition
1	$CaO – SiO_2 – Al_2O_3 – FeO$	CaO / SiO_2 1.25, Al_2O_3 4 wt%, FeO 0 – 13 wt%
2	$CaO – SiO_2 – MgO - Al_2O_3 – FeO$	CaO / SiO_2 1.5, Al_2O_3 15 wt%, MgO 10 wt%, FeO 1 - 8 wt%
3	Ladle Slags	CaO / SiO_2 9.0, Al_2O_3 40 - 43 wt%, CaF_2 14 – 20 wt%
4	Slags with $2CaO.SiO_2$ particle additions	CaO / SiO_2 1.2, FeO 24 - 30 wt% and addition of 8 – 19 wt% C_2S

Tab. 1
Range of chemical compositions of slags considered in the present study.
Composizione chimica delle scorie considerate nel presente studio.

OXIDE	(THEORETICAL) OPTICAL BASICITY
Na_2O	1.15
BaO	1.15
CaO	**1.0**
MgO	0.78
Al_2O_3	0.61
FeO	0.51
SiO_2	0.48
B_2O_3	0.42
P_2O_5	0.40

Tab. 2
Optical basicities of pure oxides, used for calculations on different slags.
Optical basicity di ossidi puri, utilizzati nei calcoli per le diverse scorie.

and reported in the literature [8-10]. Data from the literature, on chemical composition (Tab. 1) and physical properties, have been used in this paper. Slag compositions (weight percentage) were converted into mole percentage and then into equivalent fractions. These were then used to determine the optical basicity values of slags (Tab. 2). Data on bath smelting slags and ladle slags have been taken into consideration in this paper. The relevance of optical basicity to the said problem has been confirmed by tracking viscosity and surface tension as function of optical basicity [11].

RESULTS AND DISCUSSION

Experimental data on foaming index, reported by Ito and Fruehan10, for $CaO – SiO_2 – Al_2O_3$ - FeO slags, were taken for analyzing the relation between optical basicity and foaming index. The optical basicity for these (5) slags was in the range of 0.67 to 0.69 and a reasonable correlation with foaming index, with R^2 value of 0.67, was observed. Foaming index was found to increase steadily with increasing values of optical basicity (Fig. 1). This could possibly be so as high basicity slags are presumed to have low surface tension and high viscosity – which would have a stabilizing effect on the foam. Further, the surface tension values were plotted as function of optical basicity (Fig. 2). An excellent correlation, with R^2 value of 1.00, was observed. Relation between optical basicity and viscosity (R^2 = 1.00) has been reported elsewhere [7,11] and these findings justify the use of optical basicity for tracking trends in slag foaming.

Metallurgical slags, even in the same unit process, may have

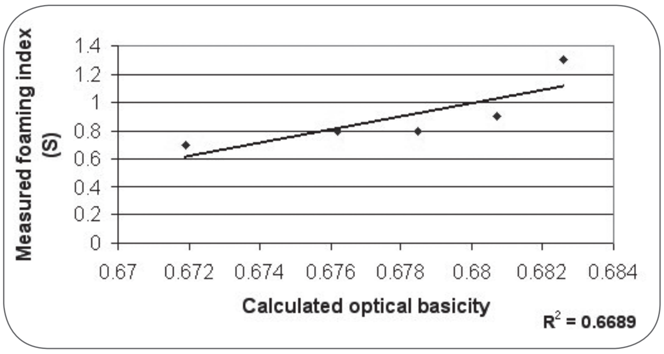

Fig. 1
Relation between calculated optical basicity[10] and measured foaming index of simplified bath smelting slags.
Relazione fra la "Optical Basicity"[10] calcolata e l'indice di formazione di schiuma per le scorie di bagni di fusione semplificati.

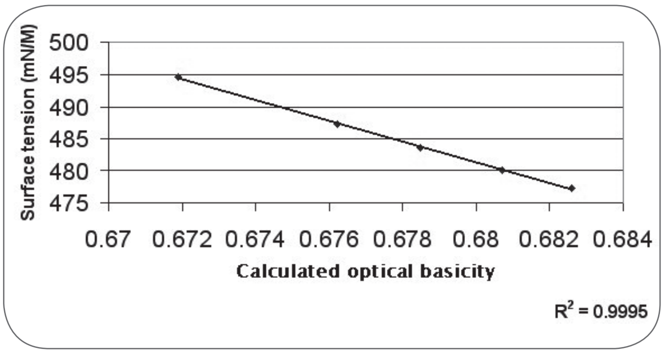

Fig. 2
Relation between calculated optical basicity10 and surface tension of simplified bath smelting slags.
Relazione fra la "Optical Basicity"10 calcolata e la tensione superficiale di schiume di bagno di fusione semplificate.

a variety of chemical compositions and hence the analysis was extended further. Experimental data of Tokumitsu et al, reported by Fruehan9,10, covering $CaO – SiO_2 – MgO – Al_2O_3$ – FeO were then analyzed. The foaming index, in this system (4 slags) (Fig. 3), was found to increase steadily with increasing values of optical basicity (0.69 to 0.70), and the correlation is very good with R^2 value of 0.91. The slags of this system, bearing 15 weight percent Al_2O_3, would be having much higher viscosities compared to the previous system, and consequently, the increased viscosity would have resulted in higher values for the foaming index. The higher nume-

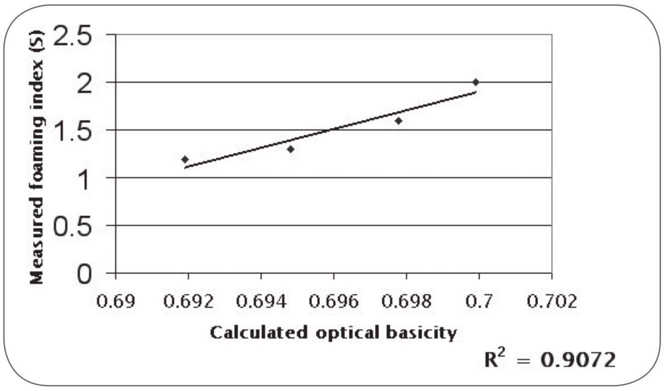

Fig. 3

Relation between calculated optical basicity and measured foaming index of bath smelting slags in CaO – SiO_2 – MgO – Al_2O_3 – FeO system.

Relazione fra la "Optical Basicity" calcolata e l'indice di formazione di schiuma misurato per schiume di bagno di fusione in sistemi CaO – SiO_2 – MgO – Al_2O_3 – FeO.

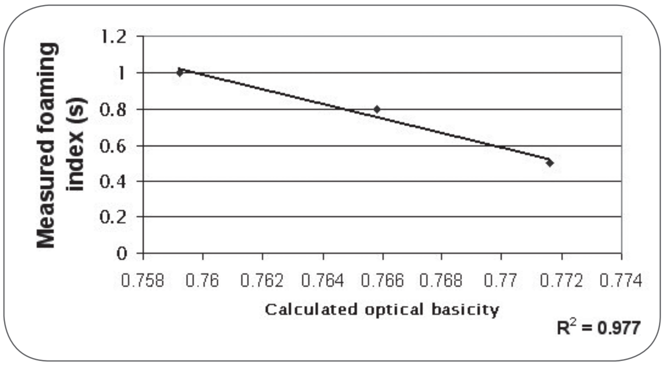

Fig. 4

Relation between calculated optical basicity and measured foaming index of ladle slags.

Relazione fra la "Optical Basicity"calcolata e l'indice di formazione di schiuma misurato per le scorie.

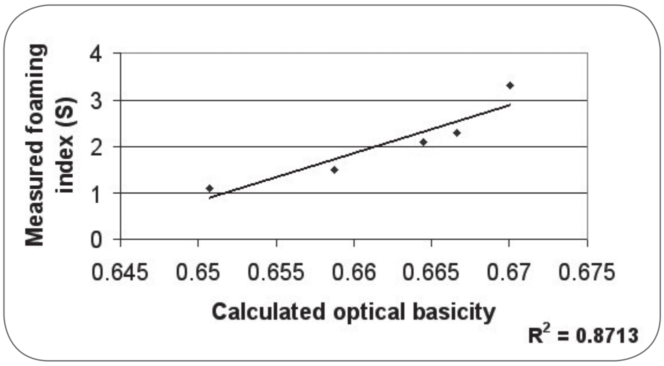

Fig. 5

Effect of addition of 2CaO - SiO2 particles on the optical basicity and measured foaming index of slags.

Effetto dell'aggiunta di 2CaO - SiO2 sull' "Optical Basicity"e l'indice di formazione di schiuma misurato per le scorie.

rical values for foaming index, in all the four cases, support this interpretation.

The analysis was then extended to ladle slags9. In this case (3 slags), the foaming index was found to decrease steadily with increasing optical basicity values (0.75 to 0.77), with an excellent correlation (R^2 = 0.98) (Fig. 4). Good correlation between surface tension and optical basicity (R^2 = 0.89)11 was observed in this case also. The reverse trend (foaming Vs optical basicity) is attributed to the presence of CaF2 in these slags, which could considerably alter the silicate structure and reduce the viscosity. This interpretation is supported by the fact that the foaming indices are lower in this system than the previous system.

Presence of oxide particles/precipitates can have a significant impact on the behaviour of slags. Slags containing di-calcium silicate additions, as reported by Jiang and Fruehan [9], were then investigated. In this system (5 points) (Fig. 5), foaming index (1-4) was found to increase steadily with increasing values of optical basicity (0.65 – 0.67). Correlation was very good, with R^2 value of 0.87. In this case, the presence of oxide particles would have increased the slag viscosity (R^2 = 1.0) [11] and this, in turn, would have stabilized the foam – resulting in the relatively higher values observed for foaming index.

CONCLUDING REMARKS

The concept of optical basicity, which is much more comprehensive of the slag composition than basicity, has been applied to study the trends in foaming of slags. The exercise has been useful as the potential for the use of optical basicity has been demonstrated. It could also be seen that the effect of oxide composition on slag structure, involving Al_2O_3 and CaF_2, has a strong influence on foaming. The relation between slag composition and structure has been reported elsewhere [12,13]. A more rigorous analysis of slag structure (Vs composition) can result in an improved understanding of slag behaviour.

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ABSTRACT

APPLICAZIONE DEI PARAMETRI DI "OPTICAL BASICITY" ALLA FORMAZIONE DI SCHIUMA NELLE SCORIE

Parole chiave: siderurgia, affinazione

Le scorie metallurgiche svolgono un ruolo importante nella fusione e affinazione di metalli. Molti ricercatori stanno compiendo sforzi per capire i fattori che influenzano le proprietà delle scorie. La "Optical Basicity" è un parametro chimico che è stata applicata ai vetri e alle scorie, e fornisce una rappresentazione più completa della composizione delle scorie rispetto alla basicità convenzionale. La formazione di schiuma è un fenomeno importante in siderurgia, tuttavia le informazioni disponibili sugli effetti della composizione delle scorie sulla formazione di schiuma sono limitate. Per le diverse scorie, sono stati calcolati valori di "Optical Basicity", a partire dalla composizione chimica - seguendo l'approccio di Duffy e collaboratori. I valori calcolati sono stati quindi in seguito applicati per seguire le tendenze alla formazione delle schiume, dei bagni di fusione e delle scorie di siviera. I risultati ottenuti dimostrano un potenziale utilizzo della "Optical Basicity" in questo settore, ma ulteriori sviluppi potrebbero essere investigati in termini di struttura e concentrazione ionica.