INFLUENCE OF SLAG BASICITY AND COOLING RATE ON THE STRUCTURE OF EAF STEELMAKING SLAGS

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Introduction

With the goal of reducing CO_2 emissions from the steel industry, the role of the electric arc furnaces (EAF) in the production of steel is likely to increase in the coming years. Hence, the amount of produced EAF slag will also increase in comparison to other steelmaking slags. In order to optimise the valorisation of solidified EAF slags, it is necessary to know how different variables affect the structure and properties of solidified slags. The aim of this study was to investigate the effect of basicity and cooling rate on the slag structure.

Materials and methods

The studied materials were synthetic slags consisting of oxides of calcium, silicon, magnesium, iron and aluminium and their compositions were chosen to correspond the composition of typical EAF slags. Basicity (i.e. CaO/SiO_2 ratio) was varied between 1.0 and 2.5. Chemicals used in the preparation of synthetic slags had the following purities: Fe_2O_3 97%, Al_2O_3 99.7%, MgO 97%, CaO 92% and SiO_2 99.5%. Chemical compositions of studied slags are presented in Table 1.

Table 1: Chemical compositions of synthetic slags used in this study (in wt%)

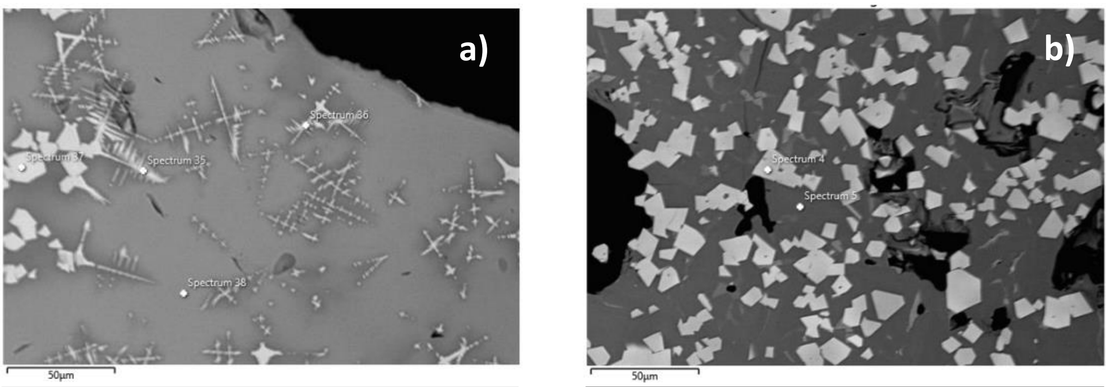
Sample	Fe_2O_3	Al_2O_3	MgO	CaO	SiO_2	CaO/SiO_2
B1	27.8	7.0	9.0	28.1	28.1	1.0
B2	27.8	7.0	9.0	33.7	22.5	1.5
B3	27.8	7.0	9.0	37.5	18.7	2.0
B4	27.8	7.0	9.0	40.1	16.1	2.5
B5	26.7	9.4	7.8	22.3	21.0	1.1
B6	34.3	7.1	8.3	23.7	13.3	1.8

Thermochemical software FactSage (version 8.1) and its databases FactPS and FToxid were used to estimate solidus and liquidus temperatures as well as stable phases as function of temperature for all the slag compositions presented in Table 1.

Mixtures of oxide materials were melted in temperatures above the estimated liquidus temperatures (between 1400 and 1500°C depending on the sample) and then cooled in either water (rapid cooling) or air (semi-rapid cooling). Structures of the polished cross-sections of solidified samples were studied with Field Emission Scanning Electron Microscopy (JEOL JSM-7900F FESEM) with an acceleration voltage of 15 kV. Aztec Feature was used to estimate the area fraction of amorphous phases in the samples. Analysed surface areas varied between 25 and 124 mm^2 for each sample. Furthermore, compositions of both glassy, amorphous phases and crystallised phases were analysed with EDS (Energy Dispersive Spectrometer) point analysis, and the results were compared with the phases that would be stable in thermodynamic equilibrium in different temperatures.

Results and discussion

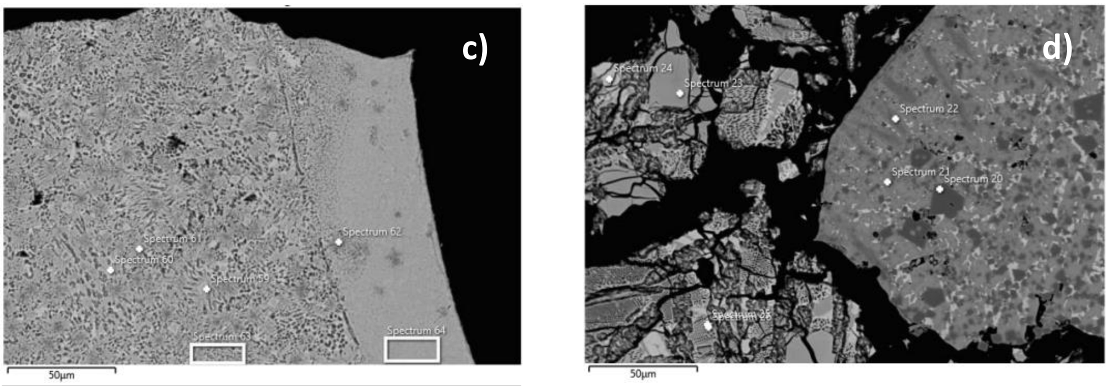
A few examples of SEM-EDS analyses are shown in Figures 1 and 2. Examples presented in Figures 1 and 2 were chosen to represent the samples with the lowest (sample B1; Figure 1) and the highest (sample B4; Figure 2) basicities investigated in this study. A summary of phases detected and computed phases is presented in Table 2. Finally, fractions of amorphous phase for slag samples with different basicities and cooling rates are presented in Figure 3, which contains results of all the studied slag compositions.



	O (wt%)	Mg (wt%)	Al (wt%)	Si (wt%)	Ca (wt%)	Fe (wt%)	Total (wt%)	Identified phase
Spectrum 37	32.22	10.93	3.68		0.61	51.84	99.28	Spinel
Spectrum 38	39.53	4.95	3.51	14.3	21.75	16.26	100.3	Amorphous

	O (wt%)	Mg (wt%)	Al (wt%)	Si (wt%)	Ca (wt%)	Fe (wt%)	Total (wt%)	Identified phase
Spectrum 4	31.76	10.3	5.06		0.65	48.85	96.62	Spinel
Spectrum 5	39.11	4.54	4.52	15.87	26.09	7.51	97.65	Melilite

Figure 1: Examples of SEM-EDS-analyses of different samples: **a)** Rapidly cooled B1 sample; **b)** Semi-rapidly cooled B1 sample. Sample B1 represents the lowest studied basicity



	O (wt%)	Mg (wt%)	Al (wt%)	Si (wt%)	Ca (wt%)	Fe (wt%)	Total (wt%)	Identified phase
Spectrum 59	32.55	12.41	7.46	0.1	1.09	43.5	97.11	Spinel
Spectrum 61	34.42	38.83	2.16	0.38	1.24	19.64	96.66	MeO

	O (wt%)	Mg (wt%)	Al (wt%)	Si (wt%)	Ca (wt%)	Fe (wt%)	Total (wt%)	Identified phase
Spectrum 21	40.37		31.02	0.44	24.44	4.41	100.68	C_2AF
Spectrum 23	34.38	13.43	14.79		0.54	34.61	97.75	Spinel

Figure 2: Examples of SEM-EDS-analyses of different samples: **a)** Rapidly cooled B4 sample; **b)** Semi-rapidly cooled B4 sample. Sample B4 represents the highest studied basicity

Table 2: Summary of expected and detected phases in studied slag systems

Sample	Basicity (CaO/SiO_2)	Equilibrium phases in order of formation	Rapid cooling	Semi-rapid cooling
B1	1.0	amorphous, spinel, melilite, clinopyrexene, corundum	amorphous (91%), spinel, corundum	amorphous (58%), spinel, melilite
B2	1.5	amorphous, spinel, melilite, bredigite, bC_2SA	amorphous (87%), spinel, bredigite	amorphous (69%), spinel, melilite
B3	2.0	amorphous, aC_2SA, spinel, bC_2SA, C_2AF, bredigite, melilite	amorphous (35%), spinel, bredigite	amorphous (16%), spinel, C_2AF, melilite
B4	2.5	amorphous, MeO, aC_2SA, spinel, bC_2SA, bredigite, C_2AF	amorphous (24%), MeO, spinel, C_2AF	amorphous (5%), spinel, C_2AF
B5	1.1	amorphous, spinel, melilite, corundum, clinopyrexene, CAFS	amorphous (90%), spinel, melilite	amorphous (52%), spinel, melilite
B6	1.8	amorphous, spinel, melilite, bC_2SA, bredigite, C_2AF, CAF_3	amorphous (58%), spinel, melilite	amorphous (21%), spinel, melilite, bC_2SA

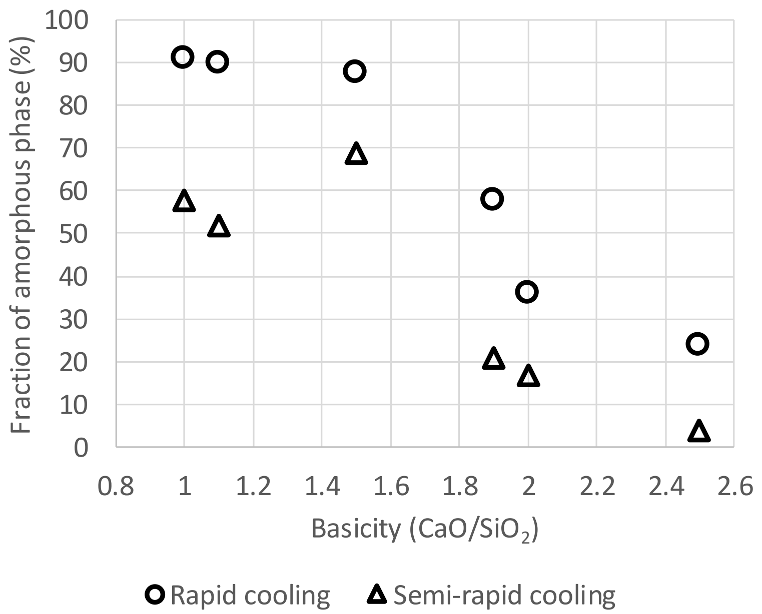


Figure 3: Fractions of amorphous phase for slag samples of varying basicity and cooling rate

Summary

Target of this study was to investigate the effect of slag basicity and cooling rate on the phase composition of solidified slags with a special focus on the formation of amorphous phase. As could be predicted based on previous studies on EAF slag structure[1,2], rapid cooling with water facilitated the formation of glassy phase in comparison with air-cooling. Furthermore, the more basic the slag was, the smaller was the portion of amorphous phase and the more complicated was the crystalline structure formed during cooling.

References

1. F Engström, B Björkman and C Samuelsson, "Mineralogical Influence of Different Cooling Conditions on Leaching Behaviour of Steelmaking Slags", in *Proceedings of the 1st International Slag Valorisation Symposium*, Leuven, Belgium, 2009. pp. 67-80.
2. F Engström, D Adolfsson, Q Yang, C Samuelsson and B Björkman, "Crystallization Behavopir of some Steelmaking Slags", *Steel Research Int*, **81** (5) 362-371 (2010).