Slag Characterization regarding Refractory Wear in EAF Steelmaking Route

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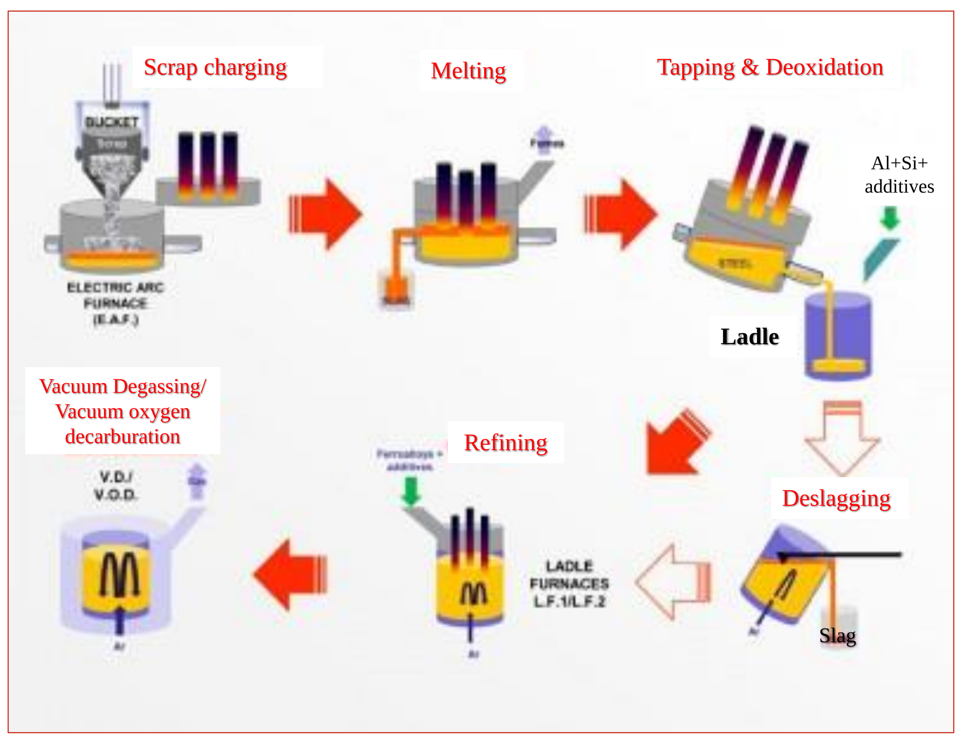
Introduction

❖ Context and problem description

Advantages

- Electric arc furnace (EAF) steelmaking route has grown in recent decades.
- EAF has the advantage of treating scraps and direct reduced iron (DRI).
- Scrap-based EAF largely contributes to reducing the environmental footprint of the steel industry, the preservation of natural resources, and sustainable production.

	tCO_2 / tLS [1,2]
EAF	0.25-1.15
BF-BOF	1.6-2.2



Electric arc furnace steelmaking route [3]

Scientific and industrial challenges

- Pre-mature failure of carbon bonded magnesia refractories occurs in different operational units such as ladle furnace (LF).
- Refractory corrosion due to chemical reactions with the slag is one of the main degradation mechanisms of the refractory.
- Refractory corrosion bears multiple costs on the process (*e.g.*, operation downtime, replacement costs for new refractory bricks, and man-hour requirements) and leads to waste generation.
- Rate and extent of chemical reactions can be complex and change based on the process's initial conditions and operational variables and need to be well understood before any improvement.

❖ Objective

The slag analysis reveals useful information about the process evolution and thermochemical and physicochemical phenomena underlying the refractory corrosion (*e.g.*, redox reactions, refractory oxide dissolution, slag viscosity and basicity). The main objective of this project is *to characterize the slag and its physicochemical properties from the two main units of EAF and LF.*

Methodology

❖ The methodology is divided into two main steps:

1) Microstructural analysis

Three slag samples from the end of EAF and the start and end of LF were collected from four different heats from the steel plant.

- Samples were dry grounded and polished using iso-propylene and 1-micron oil-based diamond suspension.
- Samples were characterized using different techniques categorized into two major groups:
  - ✓ microstructural analysis (**SEM-EDS**, EPMA, and XRD)
  - ✓ bulk chemical analysis (ICP-OES)


Slag

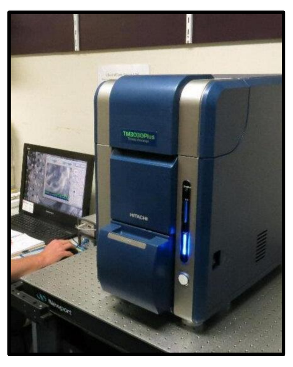
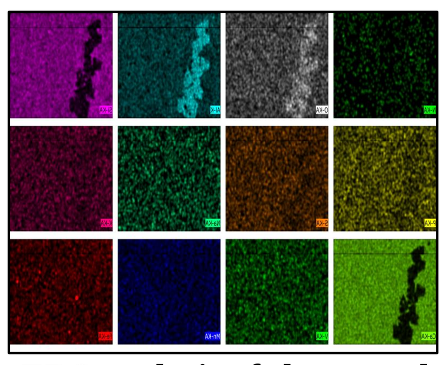


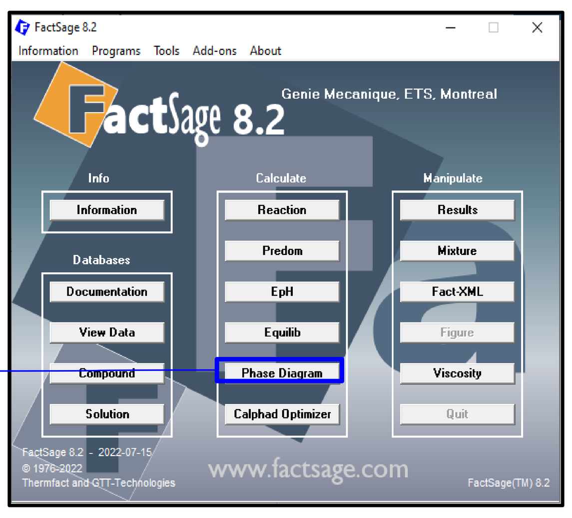
Table-top microscope


EDS analysis of slag sample

2) Thermochemical calculations using FactSage 8.2

- performed based on the slag microstructural analysis to derive further data about the slag and process (*e.g.*, basicity, MgO solubility)
- databases used in the calculations
  - ✓ FT oxid
  - ✓ Fact PS

For systems containing stoichiometric phases, solution phases, and any number of components, many types of phase diagrams can be constructed using the phase diagram module.

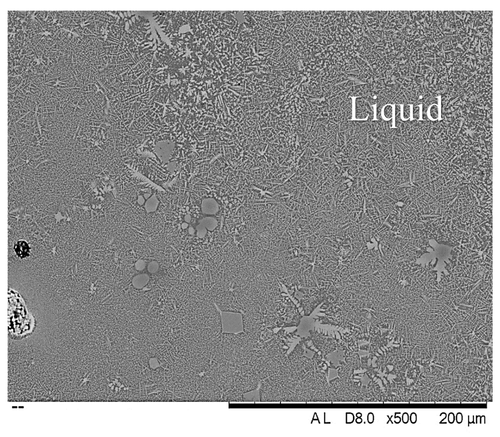


FactSage software interface

Results

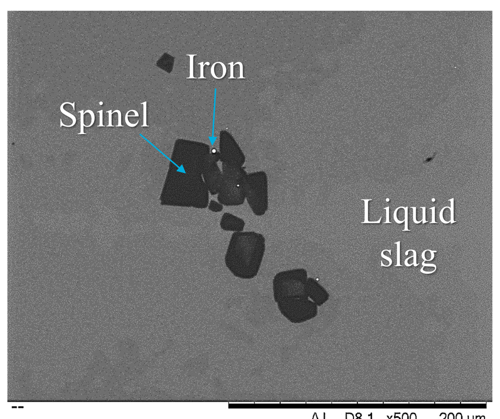
❖ BSE images of slag samples

EAF_OUT

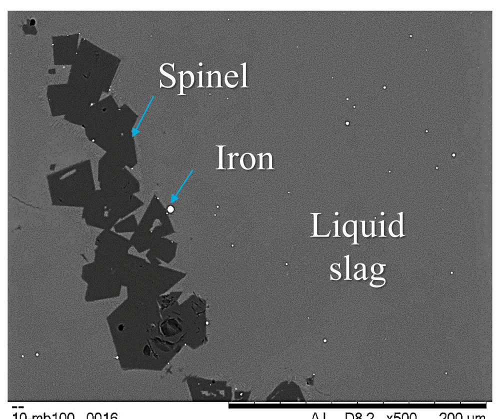


Single-phase liquid slag

LF_IN



LF_OUT



Liquid slag saturated with spinel

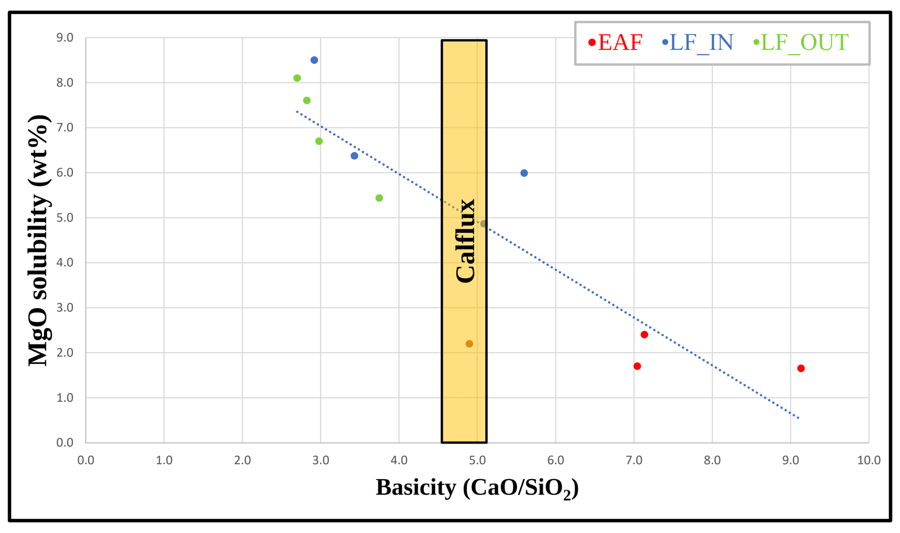
Results (continued)

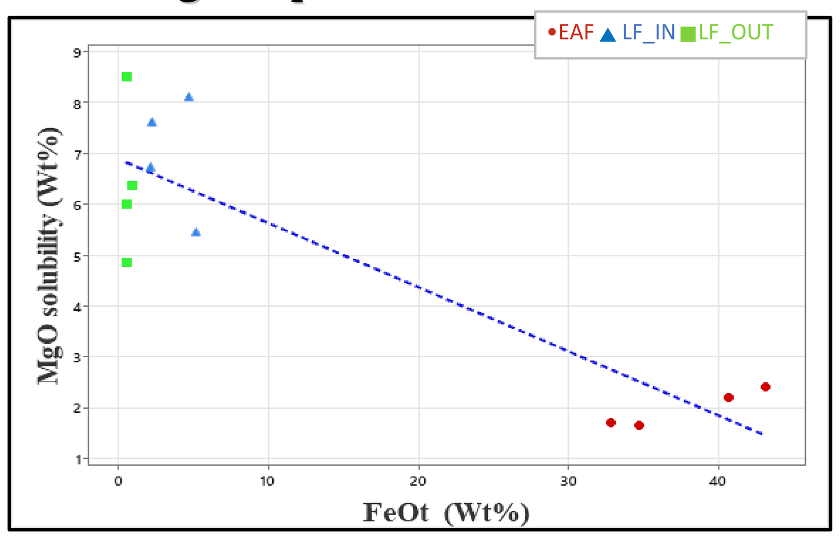
❖ Slag samples analyzed using SEM-EDS

- Possible driving forces for refractory corrosion are listed below:

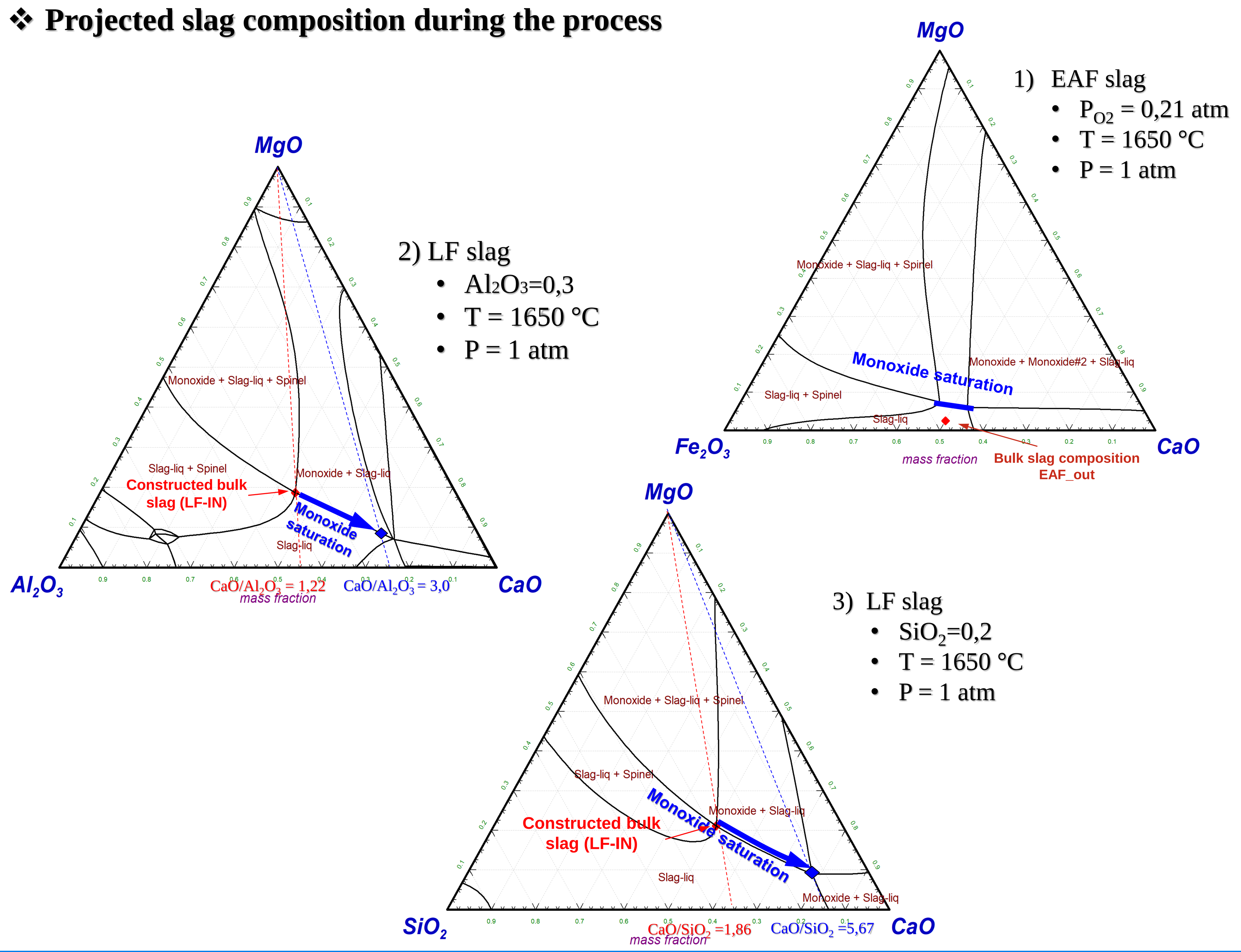
Furnace	Slag phases								Viscosity	Refractory corrosion	Driving forces	
	Liquid							Solids			Basicity (Thermodynamics)	Ar stirring (Kinetics)
	SiO_2	Al2O3	FeO_x	MnO_x	CrO_x	CaO	MgO					
EAF_OUT	6,89	2,28	40,66	8,23	6,10	33,63	2,20	✗	↓	No	4,88	No
LF_IN	16,64	22,24	4,76	2,53	0,53	45,17	8,13	✓	↑	Yes	2,72	Yes
LF_OUT	11,29	18,20	0,60	0,50	0,24	63,19	5,99	✓	↑		5,60	

❖ Solubility of MgO in slag calculated as a function of slag composition





❖ Projected slag composition during the process



Conclusions & Future work

❖ Conclusions

From the slag microstructural analysis and thermochemical calculations, the following conclusions could be derived:

- Although EAF slag is not saturated in MgO, it is not corrosive toward the refractory. In addition to the lower thermodynamic driving force, this can be explained by a lower dissolution rate of MgO in slag.
- LF slag from the plant is saturated with either spinel or spinel/monoxide solids. A slag saturated only with the monoxide phase has considerably a lower solubility for MgO.
- Thermodynamics (CaO/SiO_2 and CaO/Al_2O_3 ratios) and kinetics (bath agitation due to Ar stirring) both play a key role in the MgO solubility in slag and the refractory corrosion in LF.

❖ Future work

- Use of ICP-OES to cross-validate the bulk composition of the slag
- Collection and analysis of several more slag samples

References

[1] M. Kirschen, T. Hay, and T. Echterhof, *Process Improvements for Direct Reduced Iron Melting in the Electric Arc Furnace with Emphasis on Slag Operation.* Processes, 2021. 9(2): p. 402.
[2] N. Pardo and J.A. Moya, *Prospective scenarios on energy efficiency and CO_2 emissions in the European Iron & Steel industry.* Energy, 2013. 54: p. 113-128.
[3] https://econ243.academic.wlu.edu/2016/03/07/bof-and-eaf-steels-what-are-the-differences/ (accessed 18 August, 2022).