Comparative study of the interaction of alumina-chrome refractories with PGM smelter slag

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PGM Smelting Process

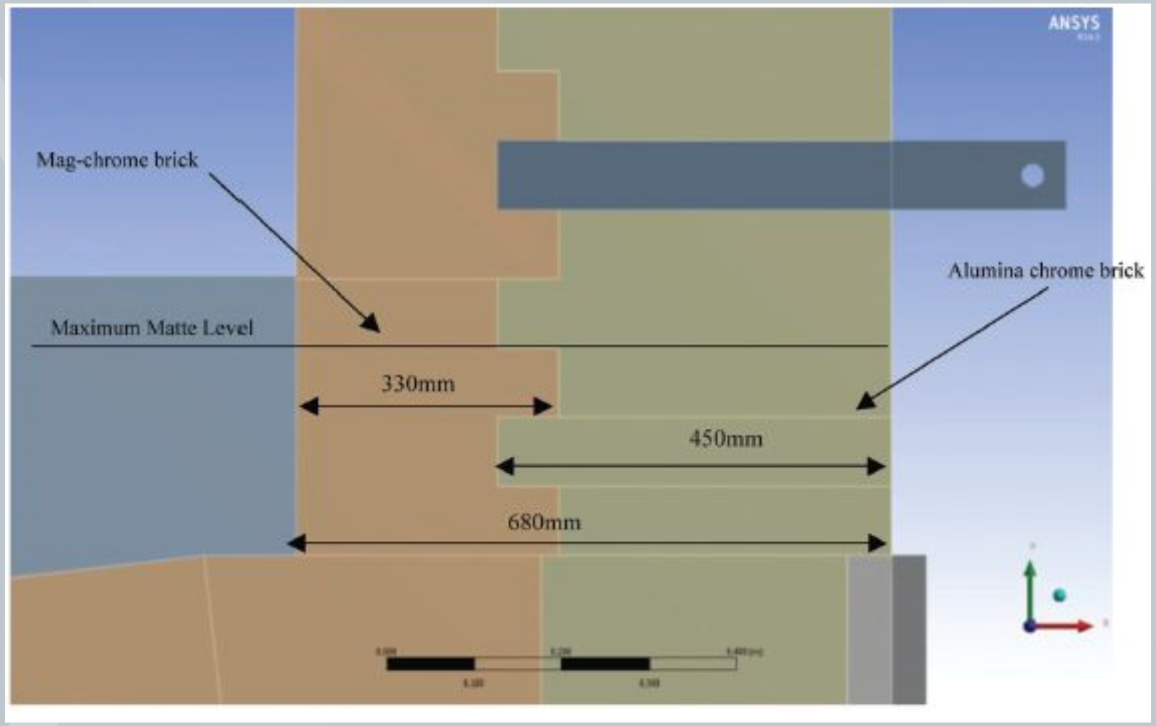
The PGM extraction process involves removing metals from their ores using a series of steps, such as comminution, flotation, smelting, and converting to produce a PGM-rich matte.

Smelting is a pyrometallurgical step that produces an Fe-S-Cu-Ni-PGM-rich matte.

The smelting process uses high temperatures to chemically transform the concentrated sulphides into valuable matte.

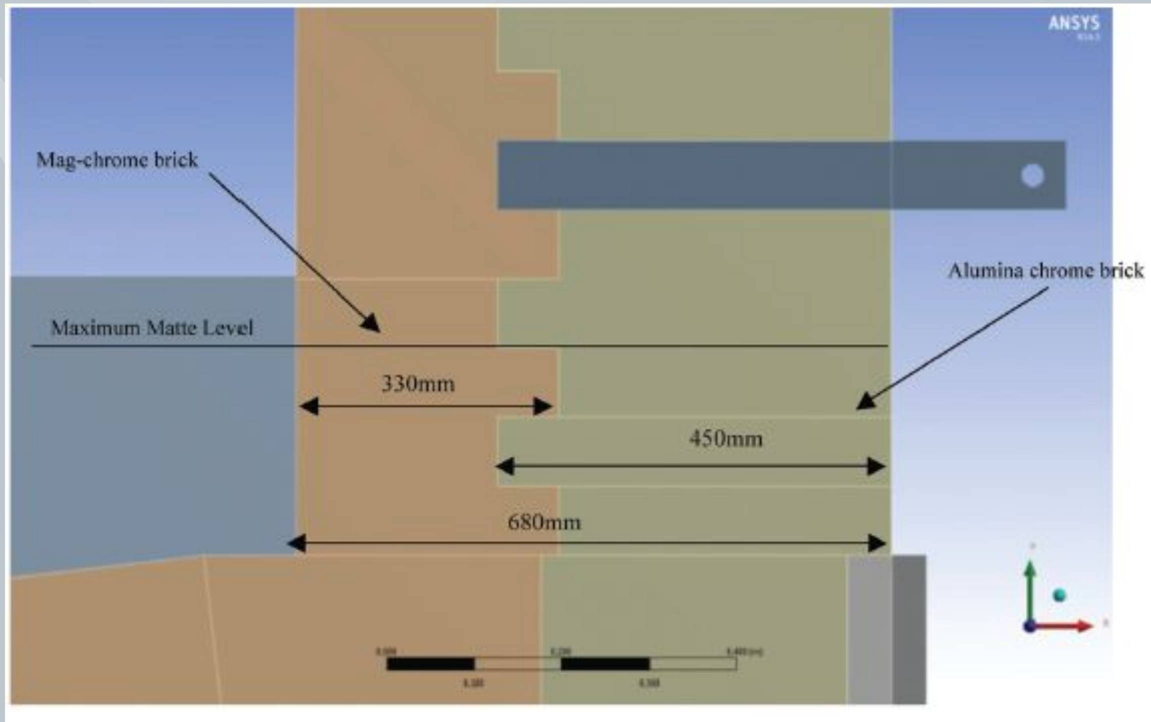
Refractories in Smelting Furnace

- Located on the lower side wall of the furnace is the area prone to refractory wear- Tidal Zone
- This is the area where the slag and matte interact.
- Layout of the tidal zone section indicating the alumina-chrome refractory bricks used as backing lining (McDougall, 2013).



Refractories in Smelting Furnace

- The slag operating temperatures vary from 1550°C to 1680°C, while matte temperatures can exceed 1500°C (McDougall *et al.*, 2021).
- In this region, the refractory material is subject to corrosion from both the slag and matte (McDougall, 2013).



Alumina-Chrome Refractories

- Alumina-chrome refractories are widely used for their thermal shock and corrosion resistance.
- Limited data on interaction with PGM smelter slag.
- Study investigates corrosion mechanisms of two commercial refractories (A and B) in TBRC furnace at 1550°C.
- Objectives: assess the influence of microstructure, composition, and phase stability on corrosion behavior.

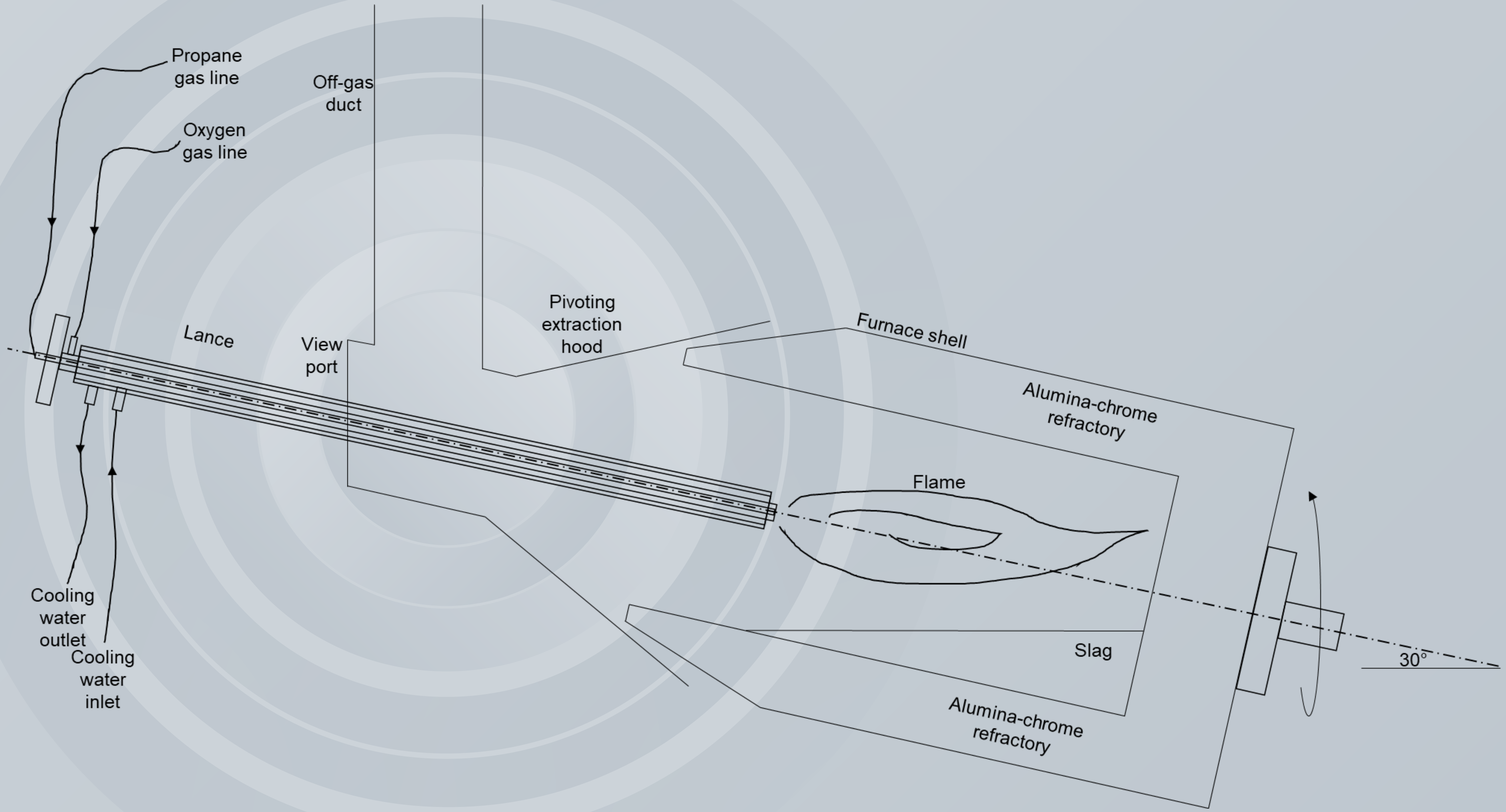
Objectives

- Compare corrosion and wear mechanisms of two Al_2O_3–Cr_2O_3 refractories.
- Analyze microstructure and chemical composition before and after slag exposure.
- Model slag–refractory interaction thermodynamically using FactSage™ 8.3.
- Identify key factors influencing slag resistance.

Experimental Setup

- Tests were performed in a **Top-Blown Rotary Converter** (TBRC) at 1550° C.
- Refractories A and B were **both** installed in the TBRC furnace.
- Temperature: 1550°C; slightly reducing O_2 flame ($pO_2 = 3.5\times10^{-6}$ atm).
- Repeated heating cycles with real PGM smelter slag.
- Dynamic slag exposure to simulate industrial conditions.
- Post-test analyses: **SEM-EDS** for microstructure and phase identification.
- **FactSage™ 8.3** used for thermochemical simulations of slag–refractory interactions.

Experimental Setup



Material Characterization

- **Refractory A**: High Al_2O_3, low Fe_2O_3 and MgO.
- **Refractory B**: Higher Cr_2O_3, Fe_2O_3, and MgO.
- Both were exposed to the same PGM smelter slag.
- Chemical compositions determined by ICP-OES.

Table 1: Chemical composition (mass%) of the slag

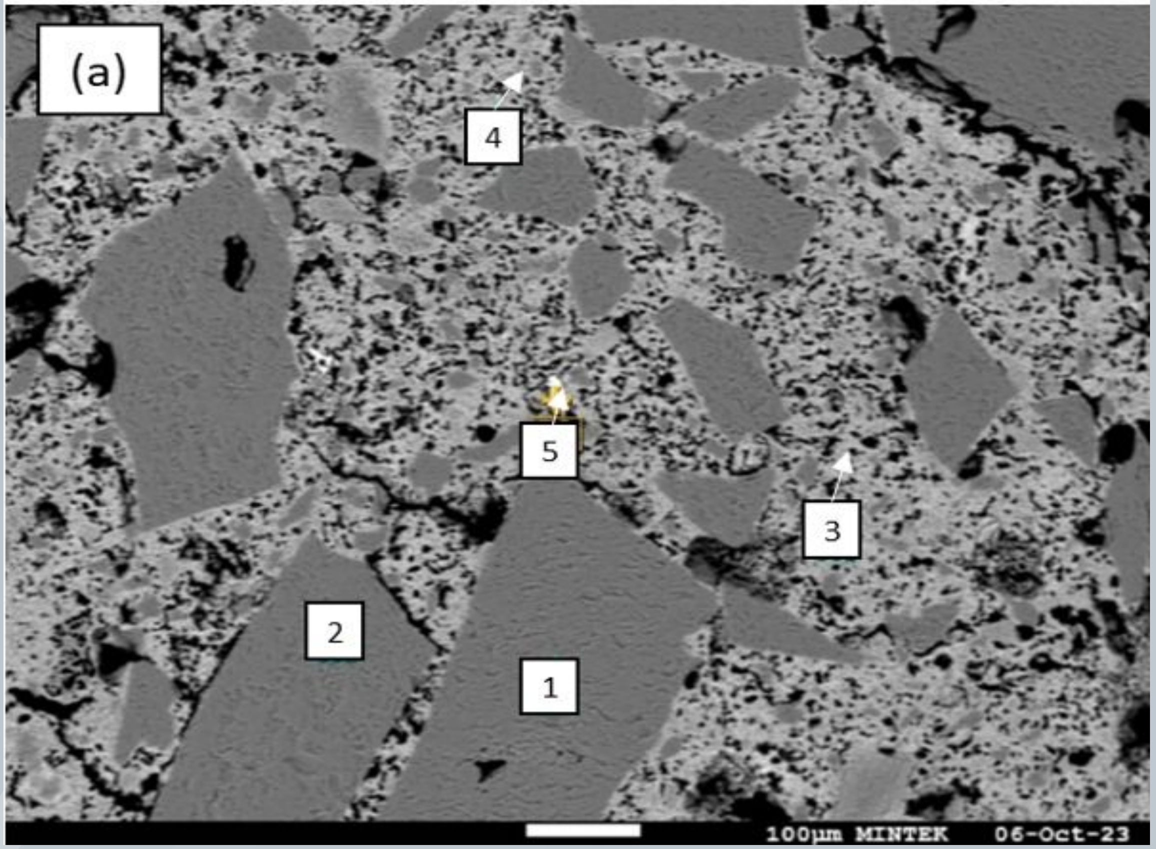
Al_2O_3	CaO	Cr_2O_3	FeO	MgO	NiO	SiO_2	S	Total
4.1	3.15	1.51	25.22	17.58	0.38	45.56	0.36	97.86

Table 2: Chemical composition (mass%) of alumina-chrome refractories

	Al_2O_3	CaO	CoO	Cr_2O_3	Fe_2O_3	MgO	SiO_2	Total
Refractory A	88.88	0.07	0.25	7.64	0.97	<0.05	2.19	100.0
Refractory B	82.65	0.10	0.29	10.31	2.76	3.12	0.56	99.79

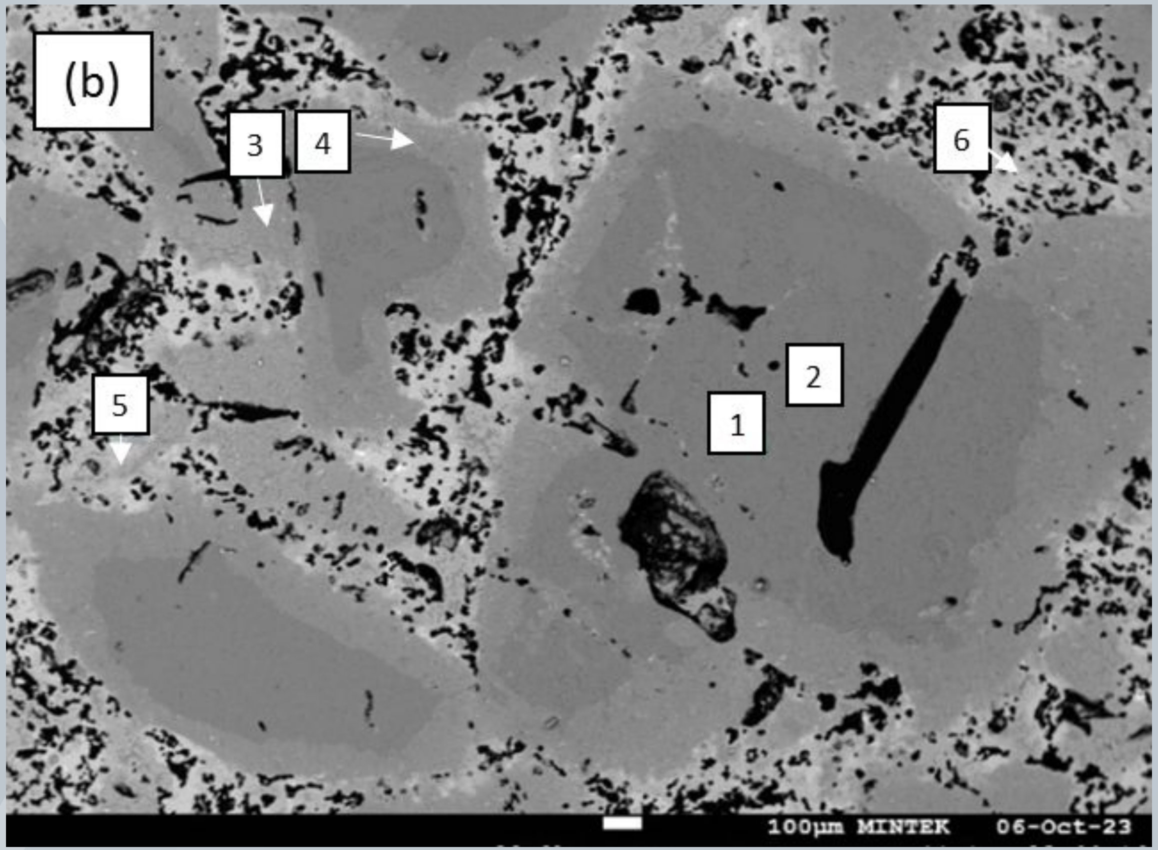
Material Characterization: Virgin Refractory

- **Refractory A**
  - Structure: large alumina grains (>100 μm) in Al_2O_3–Cr_2O_3–mullite matrix.
  - Minor phases: $ZrSiO_4$, phosphate residues



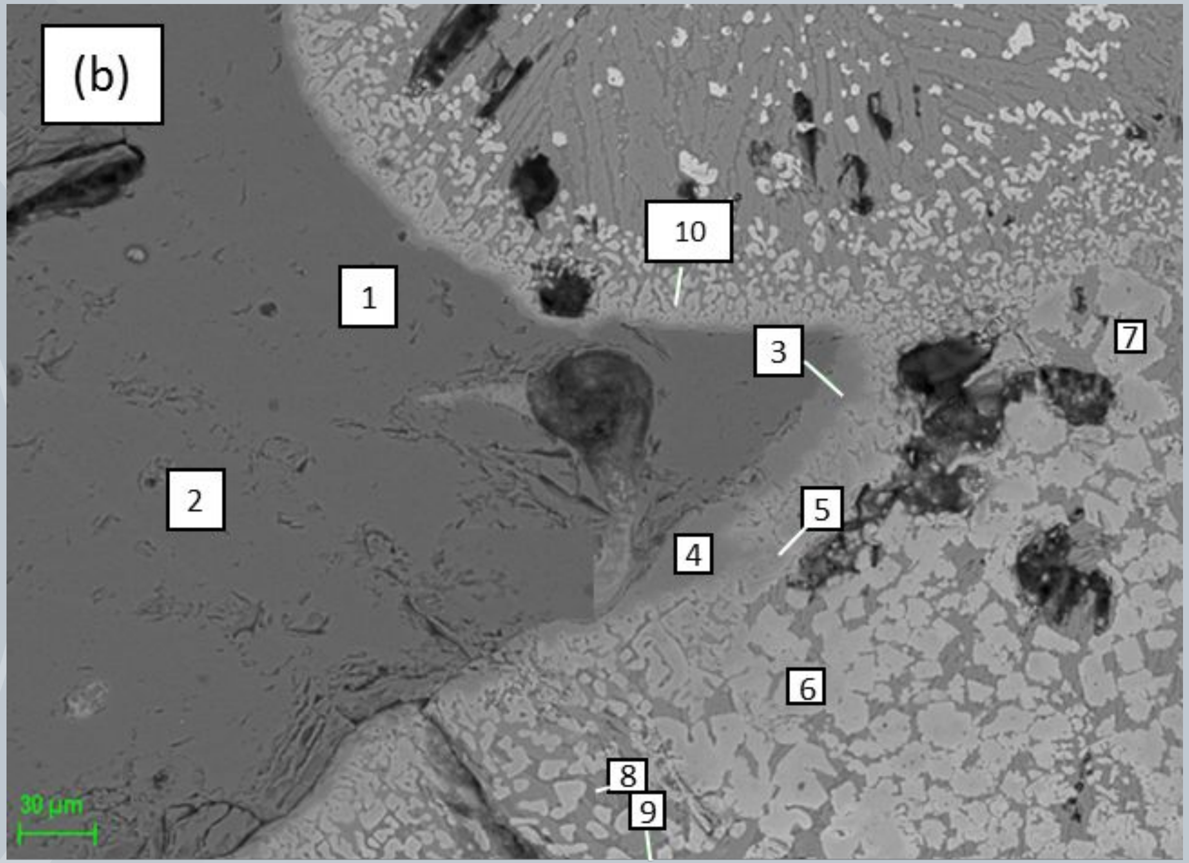
Material Characterization: Virgin Refractory

- **Refractory B**
  - Large alumina grains (~1 mm) with Cr–Fe boundary rims.
  - Matrix richer in (Mg,Fe)(Al,Cr)$_2O_4$ spinel tending towards $Fe_2Cr_2O_4$.



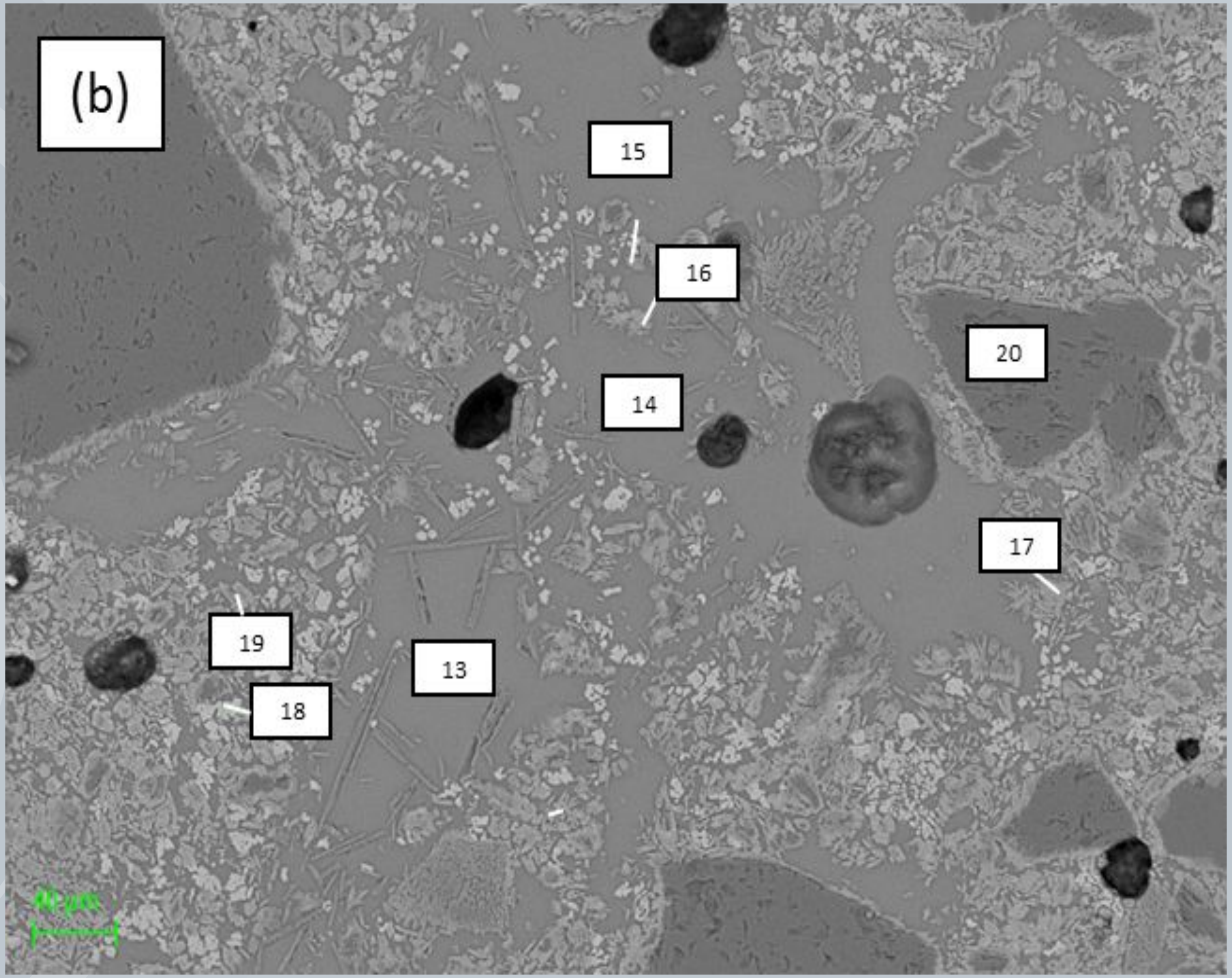
Refractory A after interaction with slag

- Formation of **fine spinel layers**:
  - $(Mg,Fe,Ni)(Cr,Al)_2O_4$ (outer layer).
  - $(Mg,Fe)Al_2O_4$ (inner, more stable layer).
- Spinel layers restricted slag infiltration and Al_2O_3 dissolution.
- Slag depleted in Fe and Mg → increased viscosity → limited penetration.
- Dense microstructure with cordierite- and feldspar-type silicates.



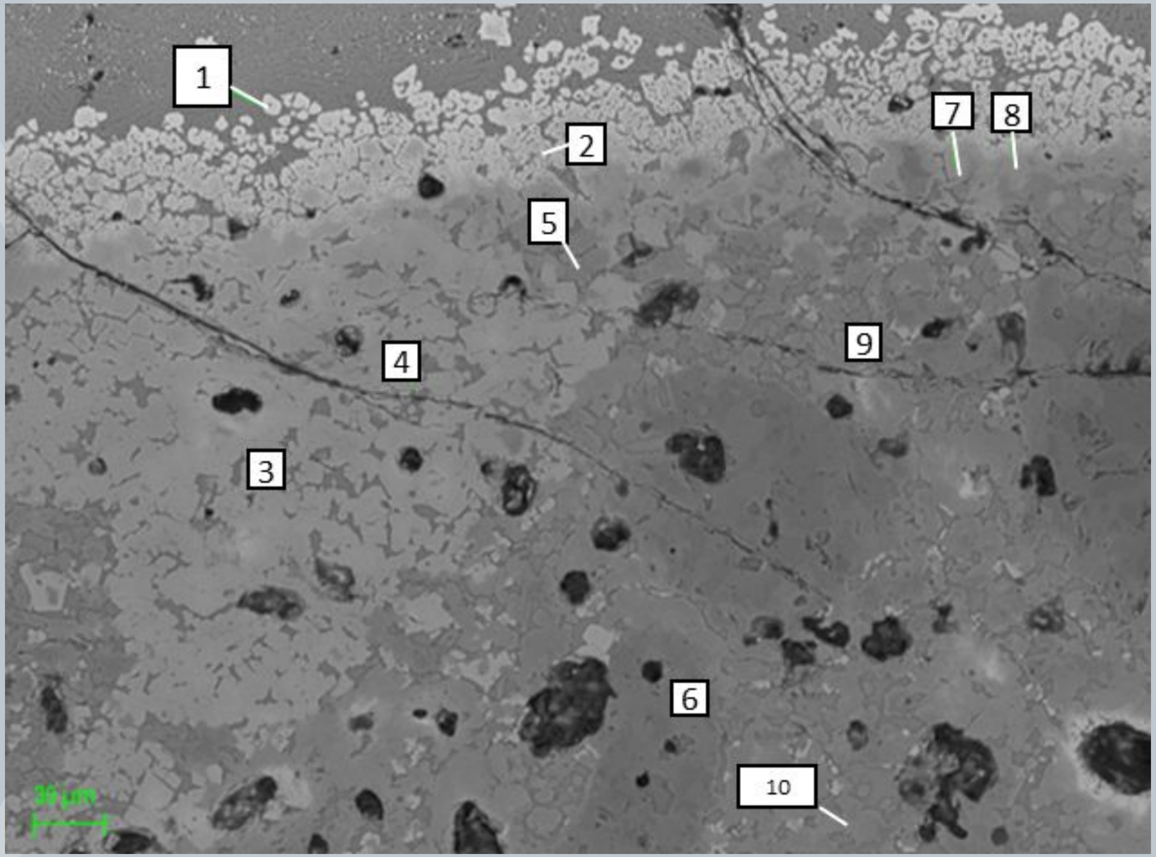
Refractory A – Precipitation zone

- Na- and P-bearing silicate phases: cordierite–feldspar solid solution.
- Increased slag viscosity reduced infiltration.
- Formation of smaller Cr-rich spinels enhanced resistance.



Refractory B-Post Exposure Results

- **Coarse spinel bands** formed at slag interface.
- Spinels: $(Fe,Mg,Ni)(Cr,Al)_2O_4$ → less protective.
- Complete dissolution of alumina grains and refractory matrix.
- New corundum solid solutions and silicate phases formed.
- Extensive chemical degradation and slag infiltration observed.
- Larger spinel particles did not inhibit slag penetration.



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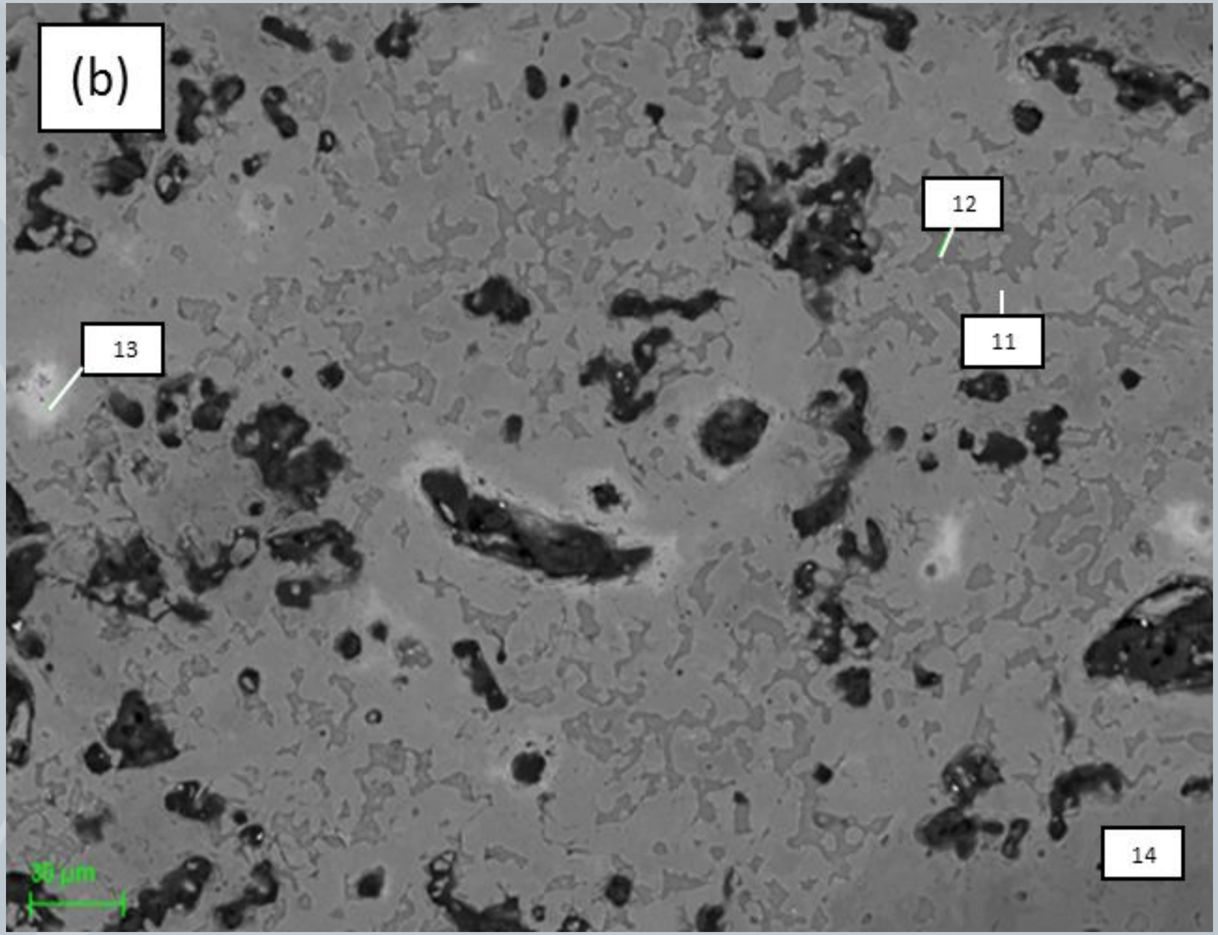
Refractory B- Reaction Zone

- Formation of (Fe,Mg,Ni)(Cr,Al)$_2$O$_4$ spinels.
- Extensive Cr enrichment and grain dissolution.
- Matrix transformed into new silicate–spinel assemblages.



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Thermodynamic Modelling (FactSage™)-Refractory A

- Corrosion mechanism dominated by **Al_2O_3 dissolution** into slag.
- **Refractory A**: Al_2O_3 saturation in slag at ~48% refractory fraction initiates corundum formation.
- MgO saturation in slag at 15.3% refractory fraction initiates spinel formation.
- MgO saturation in slag is 15.36wt%, while FeO is 22.1wt%.
- Major stable spinels: $MgAl_2O_4$ and $FeAl_2O_4$ at low slag fractions; $MgCr_2O_4$ and $FeCr_2O_4$ at high slag fractions.

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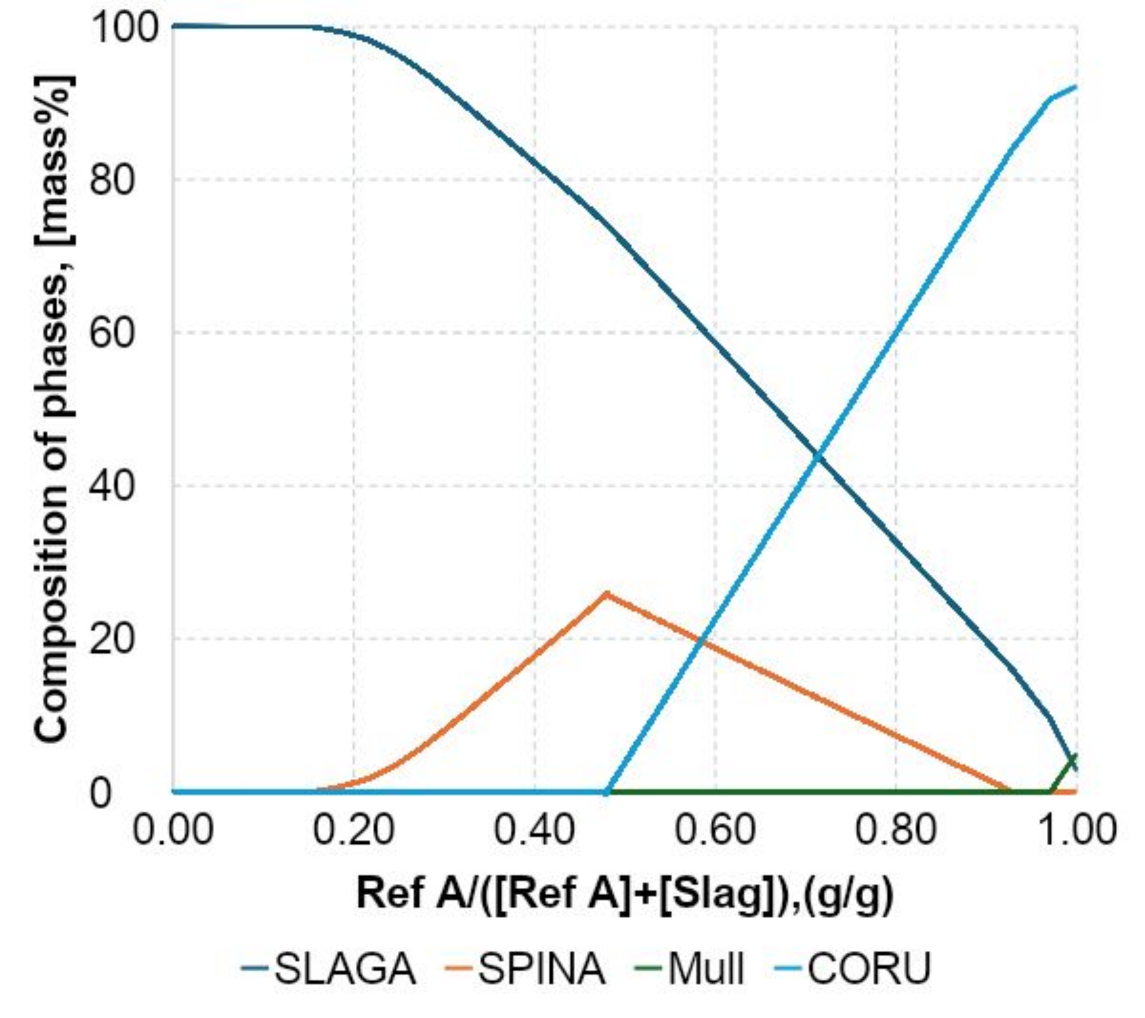
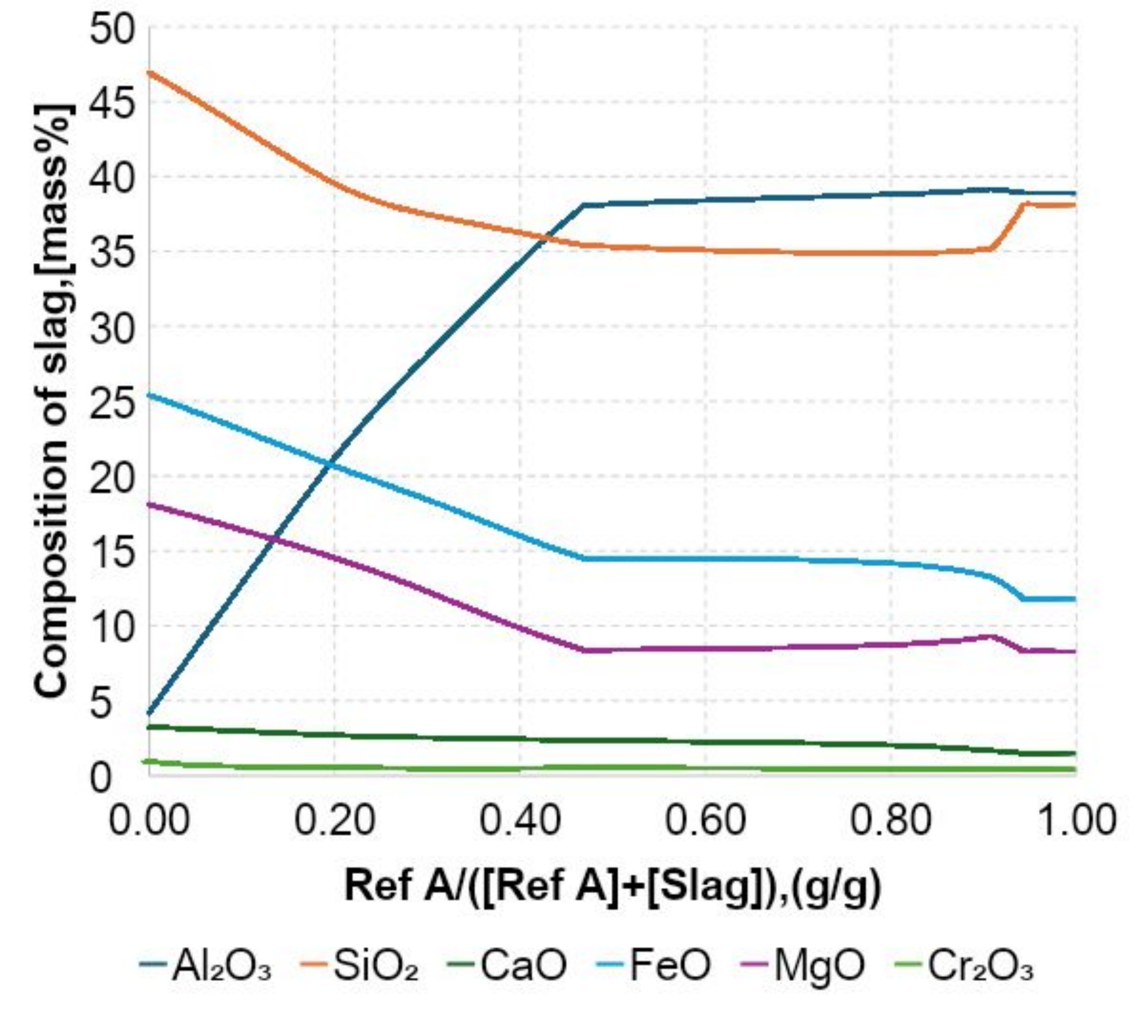
Refractory A-Slag Interface Reaction Model

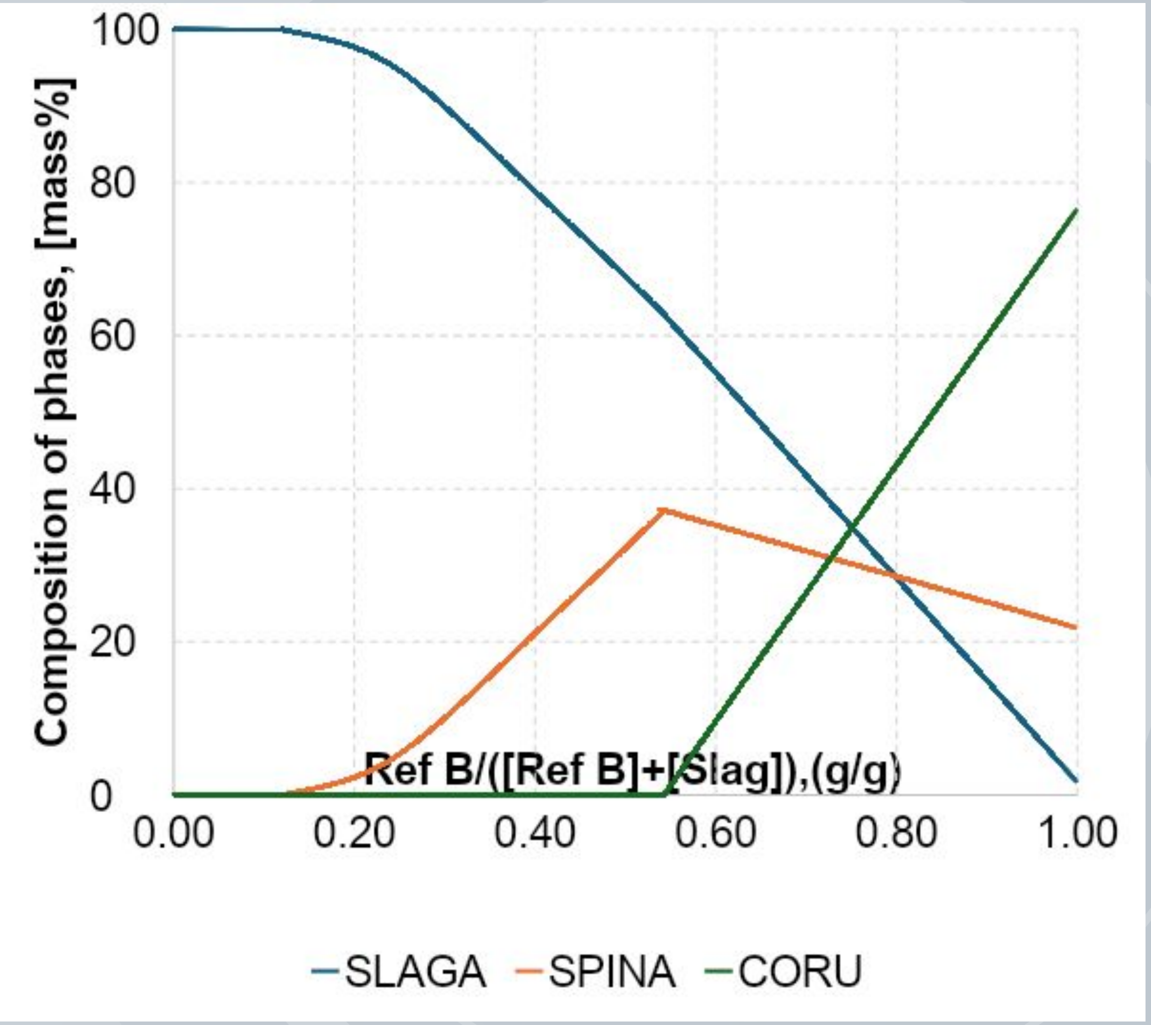


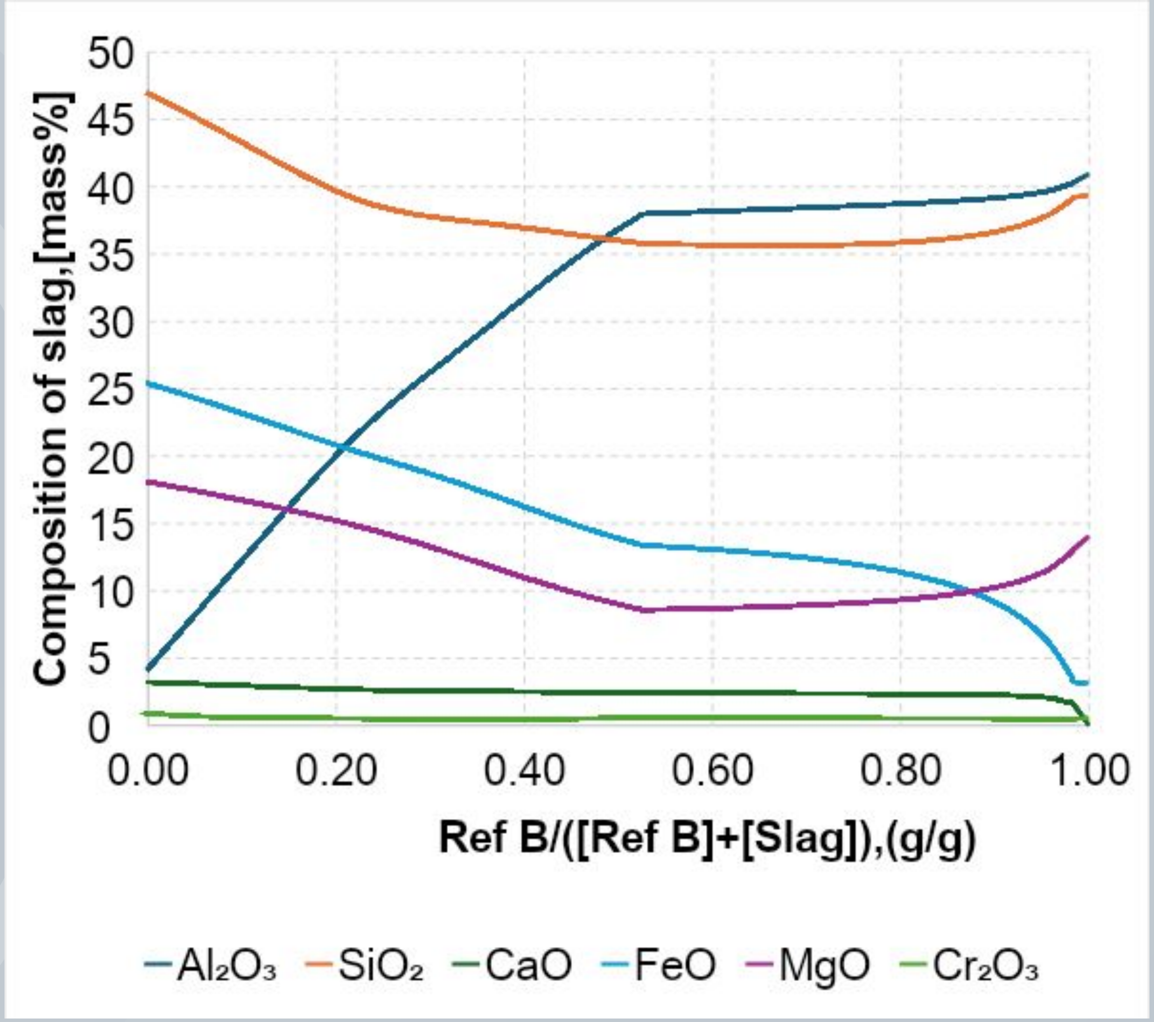


Thermodynamic Modelling (FactSage™)-Refractory B

- Corrosion mechanism dominated by **Al_2O_3 dissolution** into slag.
- **Refractory B**: Al_2O_3 saturation in slag at ~54% refractory fraction initiates corundum formation.
- Higher Fe_2O_3 and MgO promote spinel stabilization.
- MgO saturation in slag at 12% refractory fraction initiates spinel formation.
- MgO saturation in slag is 16.34wt%, while FeO is 23.1wt%
- Later corundum stabilization (54% refractory fraction) indicates a stronger driving force for dissolution → higher corrosion.

Refractory A-Slag Interface Reaction Model





Comparative Analysis

Property	Refractoiry A	Refractory B
Al_2O_3 content	Higher	Lower
Cr_2O_3 content	Lower	Higher
Spinel morphology	Fine, protective	Coarse, non-protective
Slag infiltration	Limited	Extensive
Phase stability	High	Moderate
Corrosion resistance	Superior	Poor

Corrosion Mechanisms

- Dominant mechanism: dissolution of Al_2O_3 into slag.
- Spinel formation influenced by MgO–FeO balance.
- Slag viscosity increase (due to Fe, Mg depletion) improves resistance.

Key Findings

- Corrosion mainly occurs via **Al_2O_3 dissolution**.
- **Microstructure and phase stability** critically influence performance.
- Formation of dense spinel layers improves resistance.
- Refractory A exhibited **better corrosion resistance and slower slag penetration.**

Conclusions

- **Refractory A** (high Al_2O_3, low Fe_2O_3–MgO) showed superior slag resistance.
- **Refractory A** is more suitable for PGM smelting environments due to stable high-temperature phases.
- **Refractory B** suffered severe dissolution and matrix loss.
- Corundum instability key to corrosion progression.
- Refractory design should prioritize **microstructural control** and **chemical thermodynamic compatibility** with slag.

Recommendations

Select	Select refractories based on microstructural stability and spinel formation behavior.
Favor	Favor fine-grained alumina-rich compositions.
Limit	Limit Fe_2O_3 and MgO to prevent coarse spinel formation.
Validate	Validate under real PGM smelter conditions for long-term performance.

Thank you..