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Paper name: Interaction between refractory and liquid steel regarding steel cleanliness

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Interaction between Refractory and Liquid Steel Regarding Steel Cleanliness

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Introduction

Steel cleanliness is the one unifying theme in all steel plants as problems in steel cleanliness can lead to internal rejects or customer dissatisfaction with steel products. Thus all steel plants are continually attempting to improve their practices to produce more consistent products.

Three main keys for quality steel production

- **Chemistry,**
- **Inclusion control and**
- **Rolling parameter**

Reason of Focus on inclusion

The first is their influence on the properties and the quality of steel products. This is a significant aspect from the point of view of steel product users, who have to take into account the presence of inclusions in evaluating the material behaviour in working condition.

Despite of small content of non-metallic inclusions in steel they exert significant effect on the steel properties such as:

- Tensile strength
- Deformability (ductility)
- Toughness
- Fatigue strength
- Electrical properties

Properties of Inclusion

- Thermal Expansion:
  - MnS, CaS etc. have a thermal expansion greater than steel matrix.

    - void or parting of the matrix can occur. The void act as crack
  - Al_2O_3, SiO_2, MgO, $CaO.Al_2O_3$ etc have a thermal expansion smaller than steel matrix

    - internal stresses developed

Source of Inclusion Formation

- Mechanism of inclusion formation:

Indigenous inclusions are formed in liquid, solidified or solid steel as a result of chemical reactions (deoxidation, desulfurization) between the elements dissolved in steel.

Exogenous inclusions are derived from external sources such as furnace refractories, ladle lining, mold materials etc.

Exogenous inclusions

- In industrial practice, the inclusions of MgO are found in liquid steel, and those inclusions may come from erosion of refractory lining. MgO-based inclusions are formed in steel as a result of the erosion of vessel lining refractory or as a chemical reaction product.

- Erosion of refractories, is a very common source of large exogenous inclusions which are typically solid and related to the materials of the ladle and tundish themselves. They are generally large and irregular-shaped.

Exogenous inclusions

- Exogenous inclusions have the following common characteristics:
- ➢ Large size: Inclusions from refractory erosion are generally larger than those from slag entrainment.
- Compound composition/ multiphase, cause by the following phenomena:
- Due to the reaction between molten steel and SiO_2, FeO, and MnO in the slag and lining refractory, the generated Al_2O_3 inclusions may stay on their surface;

Exogenous inclusions

- As exogenous inclusions move, due to their large size, they may entrap deoxidation inclusions such as Al_2O_3 on their surface
- Exogenous inclusions act as heterogeneous nucleus sites for precipitation of new inclusions during their motion in molten steel
- Slag or reoxidation inclusions may react with the lining refractories or dislodged further material into steel.
- Irregular shape, if not spherical from slag entrainment or deoxidation product silica. The spherical exogenous inclusions are normally large (>50μm) and mostly multiphase, but the spherical deoxidation inclusions are normally small and single phase.

Exogenous inclusions

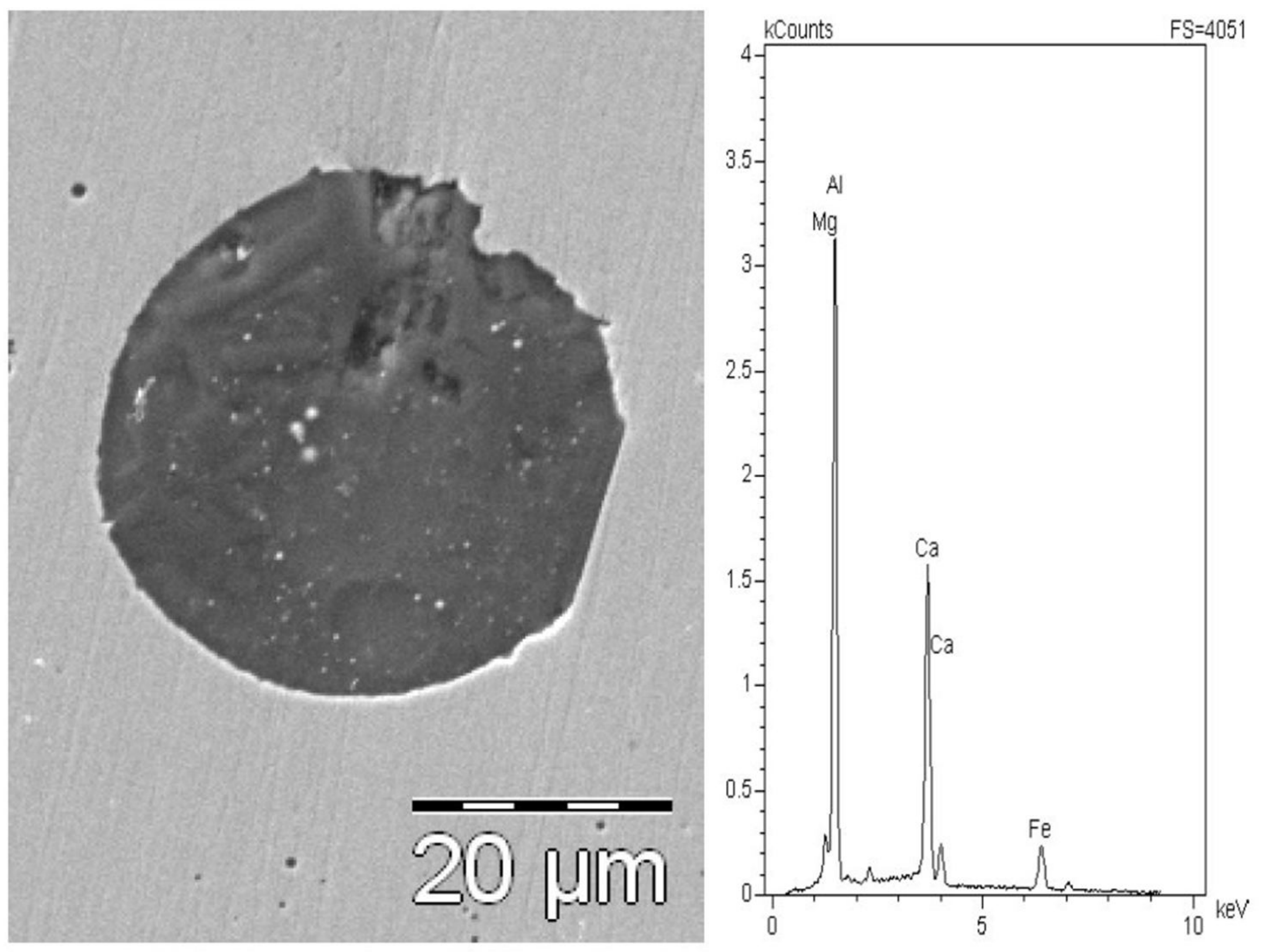
- MgO-containing solid or liquid inclusions, such as magnesia (MgO), spinel (MgO _Al_2O_3), forsterite (2MgO _ SiO_2), and (3CaO _ Al_2O_3)-MgO clusters are formed during steelmaking processes, deoxidation treatment or by reactions with MgO rich alkaline slags.

- The steel/slag reaction time influences strongly the type, composition, and shape of inclusions. With increase of reaction time, solid blocky/rectangular-shaped MgO_ Al_2O_3 and MgO-based inclusions were transferred into CaO–MgO–Al_2O_3 system inclusions with a low melting temperature <1500 _C.

Exogenous inclusions

- They change their shape to semi-spherical or spherical. The solid magnesia and spinel inclusions "would be inevitably and gradually transferred into complex liquid inclusions even dissolved [Ca] is as low as 0.0002%". Inclusions with an MgO_ Al_2O_3 or Mg-based core surrounded by a CaO–Al_2O_3 surface layer with a lower melting temperature were detected.
- In addition, depending on the quality of the used magnesite in the refractory and the slag composition, the proportion of SiO_2 and CaO leads to low melting compounds at processing conditions. Thus, the corrosion of the refractory material is promoted.

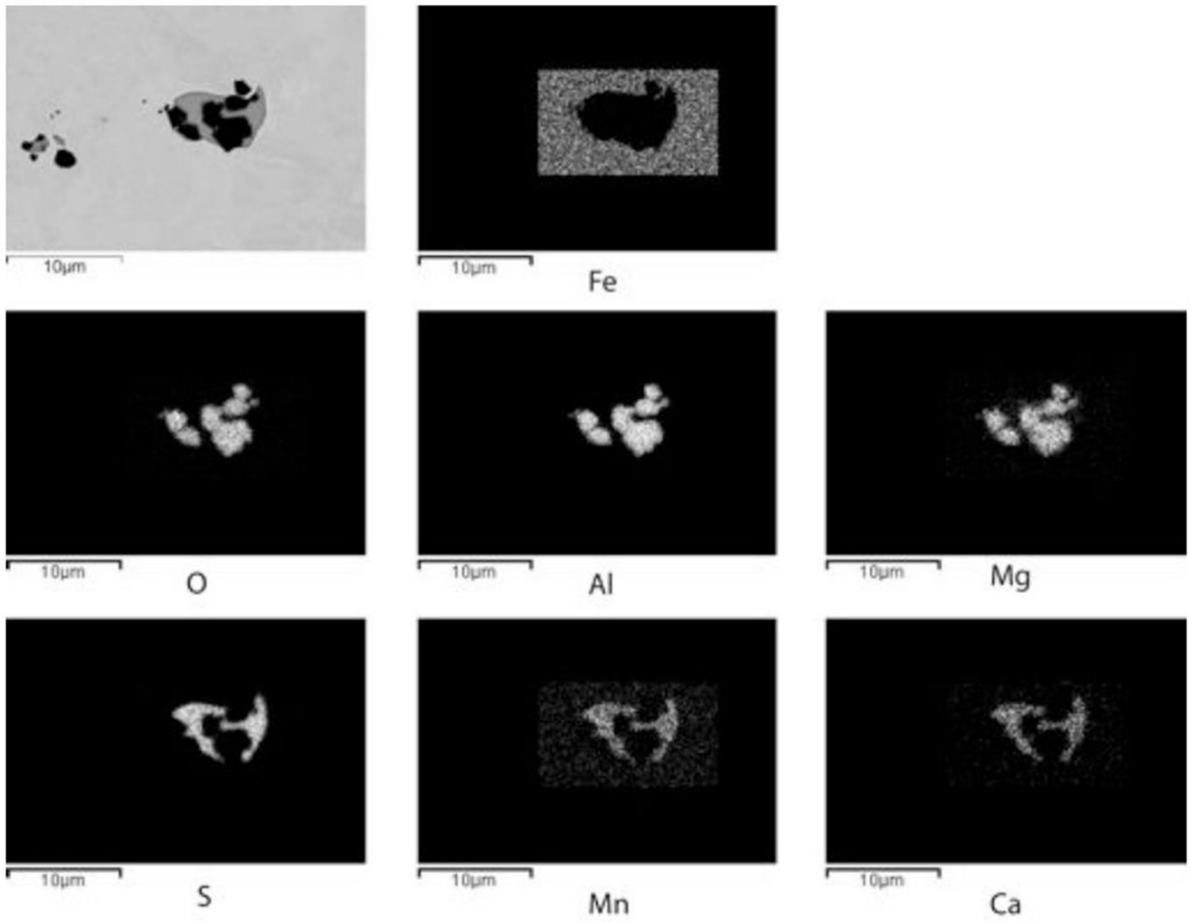
Oxide Inclusion



Steel composition:
0.10% C,
0.64% Mn,
0.01% P,
0.005% S,
0.13% Si,

Oxide inclusions

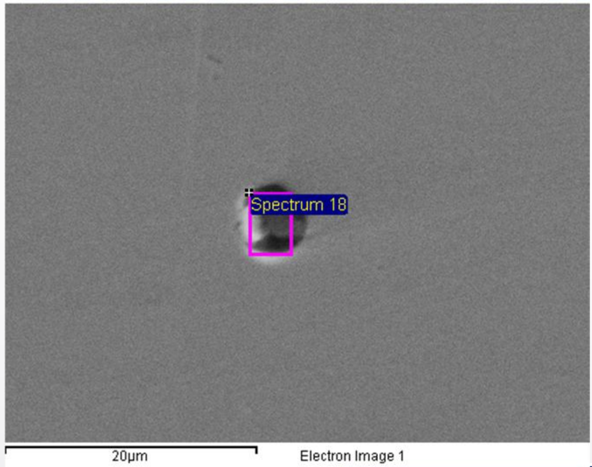
complex oxy-sulfide inclusion in steel

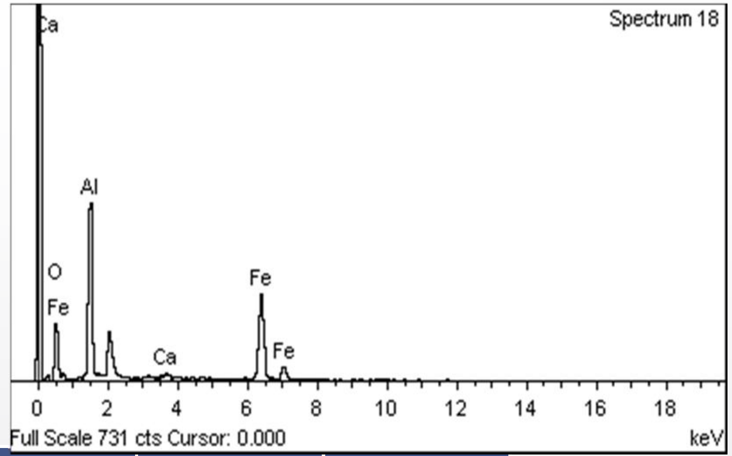


Inclusion name: Complex inclusions
Inclusion type: Micro
Inclusion classification: Oxide, sulfide, nitride
Steel composition in weight %: 0.097% C, 0.10% Si, 0.29% Mn, 0.015% P, 0.004% V, 0.027% Al, 0.008% S.

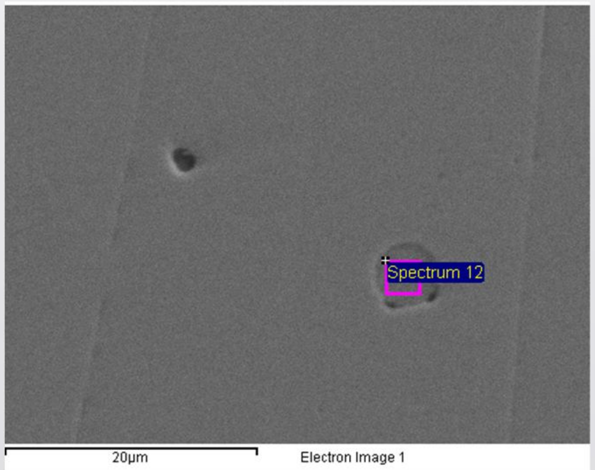
Complex non-metallic inclusions are considered to have at least a combination of oxide-sulfide or oxide-carbonitride or sulfide-carbonitride inclusions.
Therefore, the detected complex inclusions in the samples were classified into the following five groups: Al_2O_3-CaO-S, Al_2O_3-MgO-(Mn,Ca)S, Al_2O_3-MgO-MnS, MnS-(Ti,V)CN and Al_2O_3-(TiV)CN.

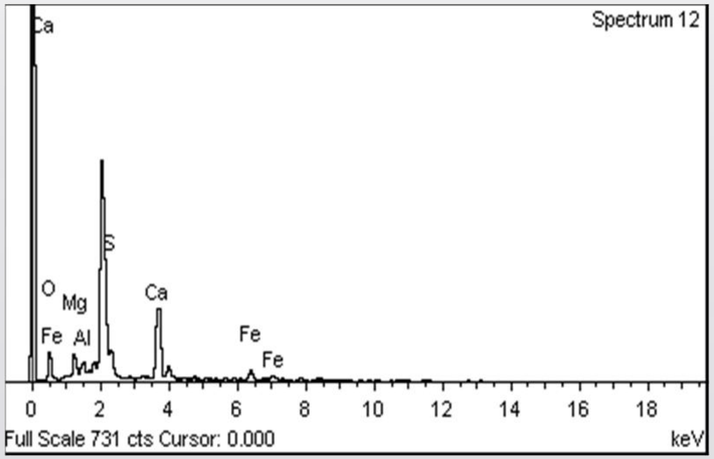
Inclusion Characterization in SEM and EDS





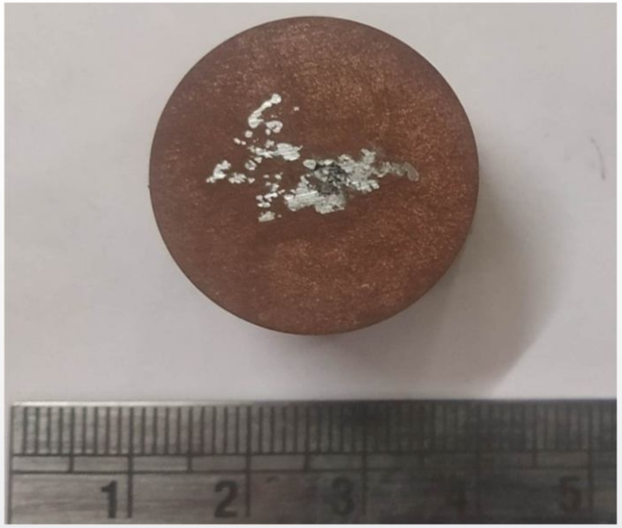
Element	O	Al	Ca	Fe
Weight%	22.29	30.17	1.01	46.53





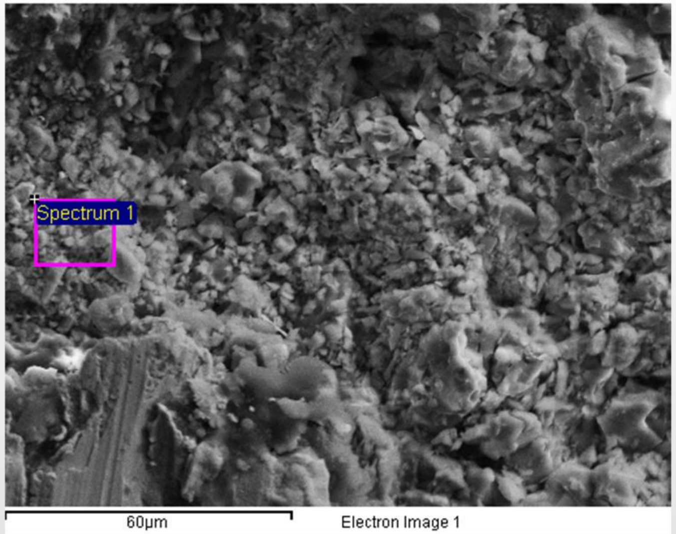
Element	O	Mg	Al	S	Ca	Fe
Weight%	44.41	7.25	3.16	7.13	28.04	10

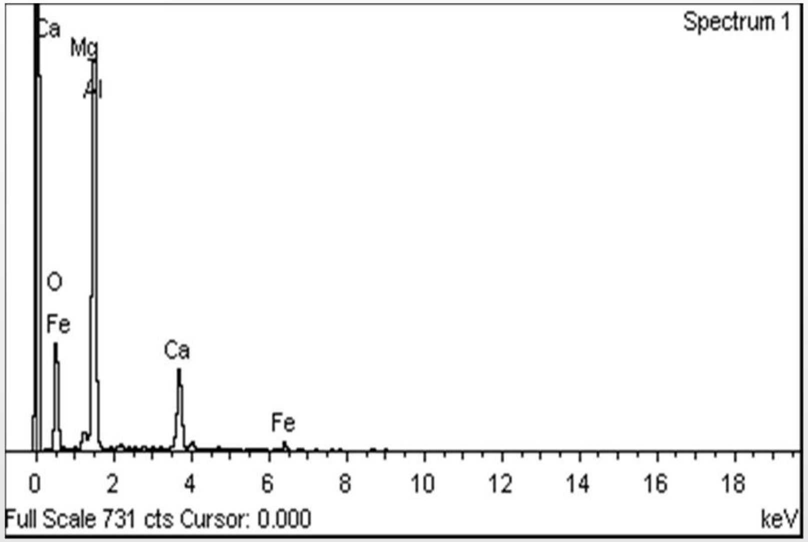
SEN Clogging Material



Sample	MgO%	Al_2O_3%	Fe_2O_3%
SEN Clog	5.06	47.23	37.94

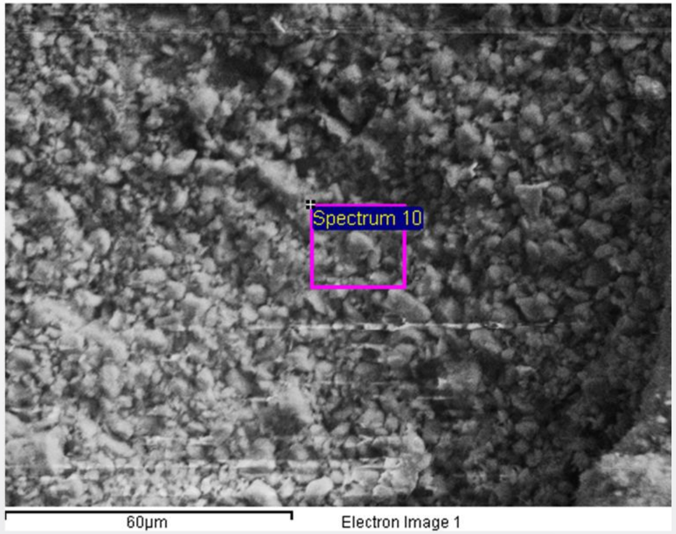
SEN Clogging Material

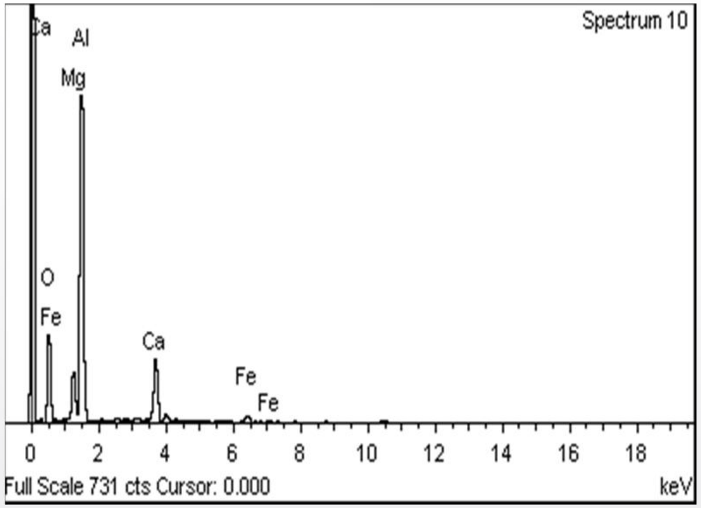




Element	O	Mg	Al	Ca	Fe
Weight%	46.88	1.59	36.92	12.15	2.46

SEN Clogging Material





Element	O K	Mg K	Al K	Ca K	Fe K
Weight%	42.91	5.67	36.97	11.1	3.36

The clogged material analysis showed the material are close in chemical nature with the inclusions in steel. High amount of calcium Aluminates in both inclusion and clogged material was found along with some Alumina-MgO spinel. Spinel may be generated with the interaction with refractory and steel alumina inclusions.

Conclusion

- Presence of MgO in calcium aluminate inclusions often indicates exogenous sources since calcium containing deoxidizers are generally magnesium free. Calcium inclusions with high MgO content most likely originate from magnesia refractories by erosion or by reaction between slag and refractories.

Thank You

International Conference on Future of Refractories in Iron & Steel Industries

23-24 Sep 2022, Bokaro Steel City