Active and passive tracing of non-metallic inclusions in steel using rare earth elements

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Introduction

Non-metallic inclusions (NMIs) negatively affect both physical and corrosive properties of steels, to the point of material failure (Fig. 1). In addition, clogging, i.e. the aggregation of non-metallic particles during the steel casting process, can further reduce steel quality or even interrupt the process (Fig. 2). [1] Within the present study, we investigated the formation of NMIs and clogging in titanium stabilised ultra-low carbon (Ti-ULC) steel, a material mainly used for automobile panels (Fig. 3).

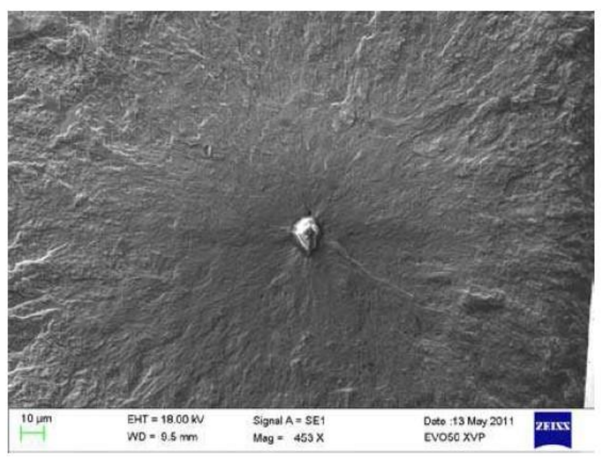


Fig. 1: *SEM image of a non-metallic inclusion (NMI) in steel which has caused cracking.*

Fig. 2: *Clogging at the submerged entry nozzle (SEN)*

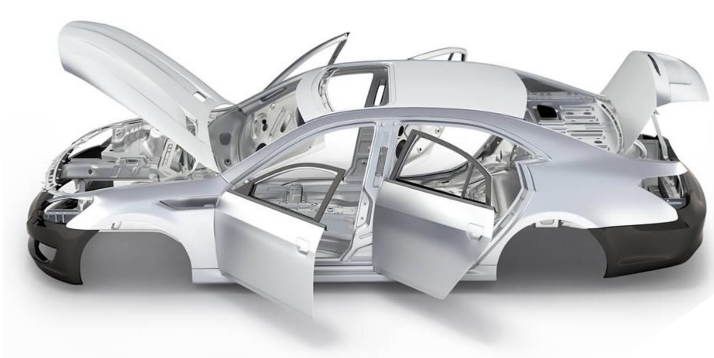
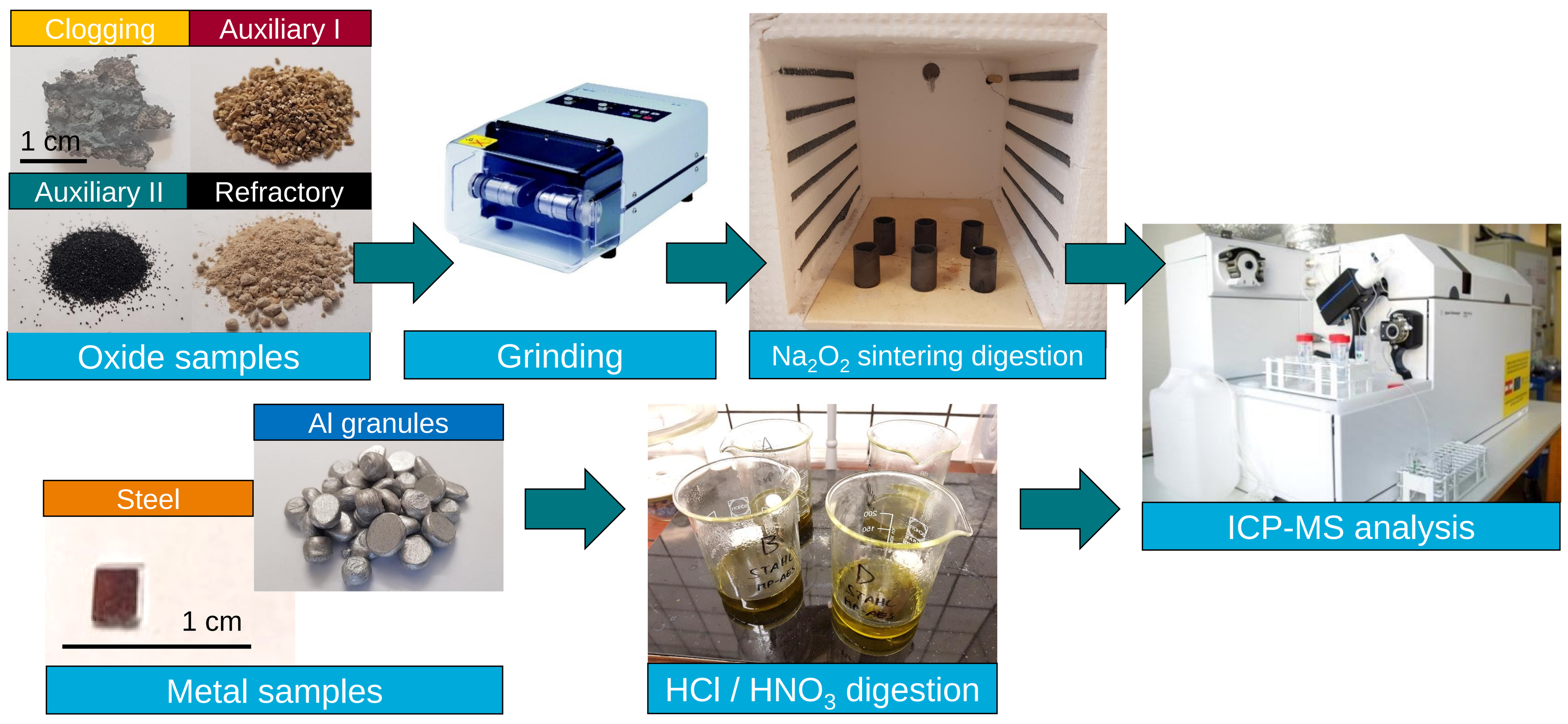


Fig. 3: *Automobile panels as an example for the use of Ti-ULC steel. [2]*

Sample preparation for ICP-MS analysis



Passive tracing

In the passive tracing approach, distribution patterns (chondrite normalised mass fractions [3]) of the rare earth elements (REE) in clogging material from the SEN and potential source materials are compared.

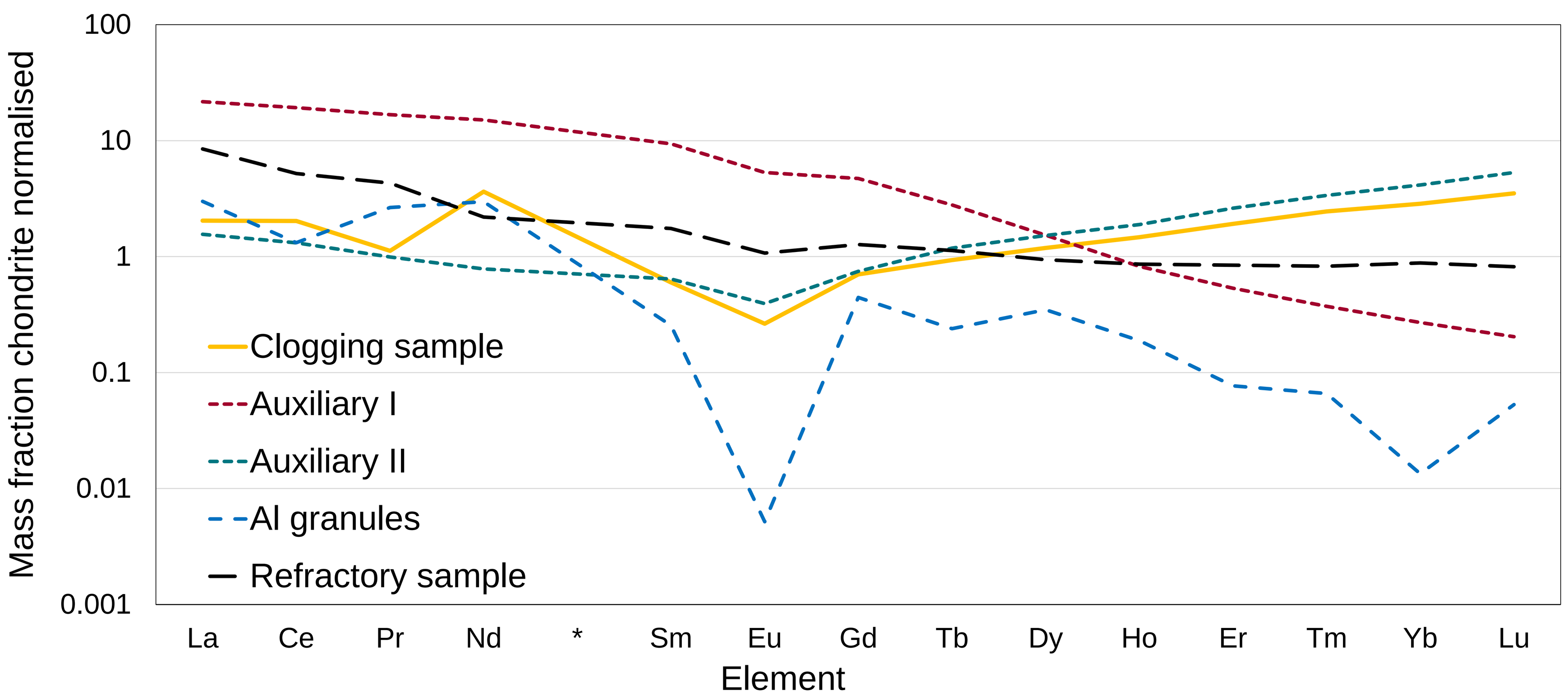


Fig. 4: *Chondrite normalised REE mass fractions determined using ICP-MS after Na_2O_2 sintering or HCl/HNO_3 digestion in SEN clogging material and reference samples. Values for Pm (*), which does not occur naturally, were interpolated between Nd and Sm.*

- Similar trends are visible in the REE patterns of auxiliary material II (sliding gate sand) and the clogging sample.
- Both Al granules (added for deoxidation) and clogging sample have high Nd and low Eu contents.
- Clogging formation can be explained by a combination Al_2O_3 (oxidised Al granules) and silicate components of the sliding gate sand.

References

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[2] Picture source: https://www.ebmeyer.eu/referenzen/projekte/

[3] Wasson, J. T., & Kallemeyn, G. W. (1988). Compositions of chondrites. *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences*, *325*(1587), 535-544.

[4] Burty, M., Dunand, P., Ritt, J. P., Soulard, H., Blanchard, A., Jeanne, G., ... & Poissonnet, I. (1997, April). Control of DWI steel cleanness by lanthanum tracing of deoxidation inclusions, ladle slag treatment and a methodical approach. In *Ironmaking Conference Proceedings.* (Vol. 56, pp. 711-717).

Results & Conclusions

- Results gained using both the active and passive tracing approach consistently link the clogging material from the SEN to the aluminium added in the deoxidation step.
- Agglomeration of aluminium oxide particles is the main reason for clogging during the Ti-ULC steel casting process.

Steel production process

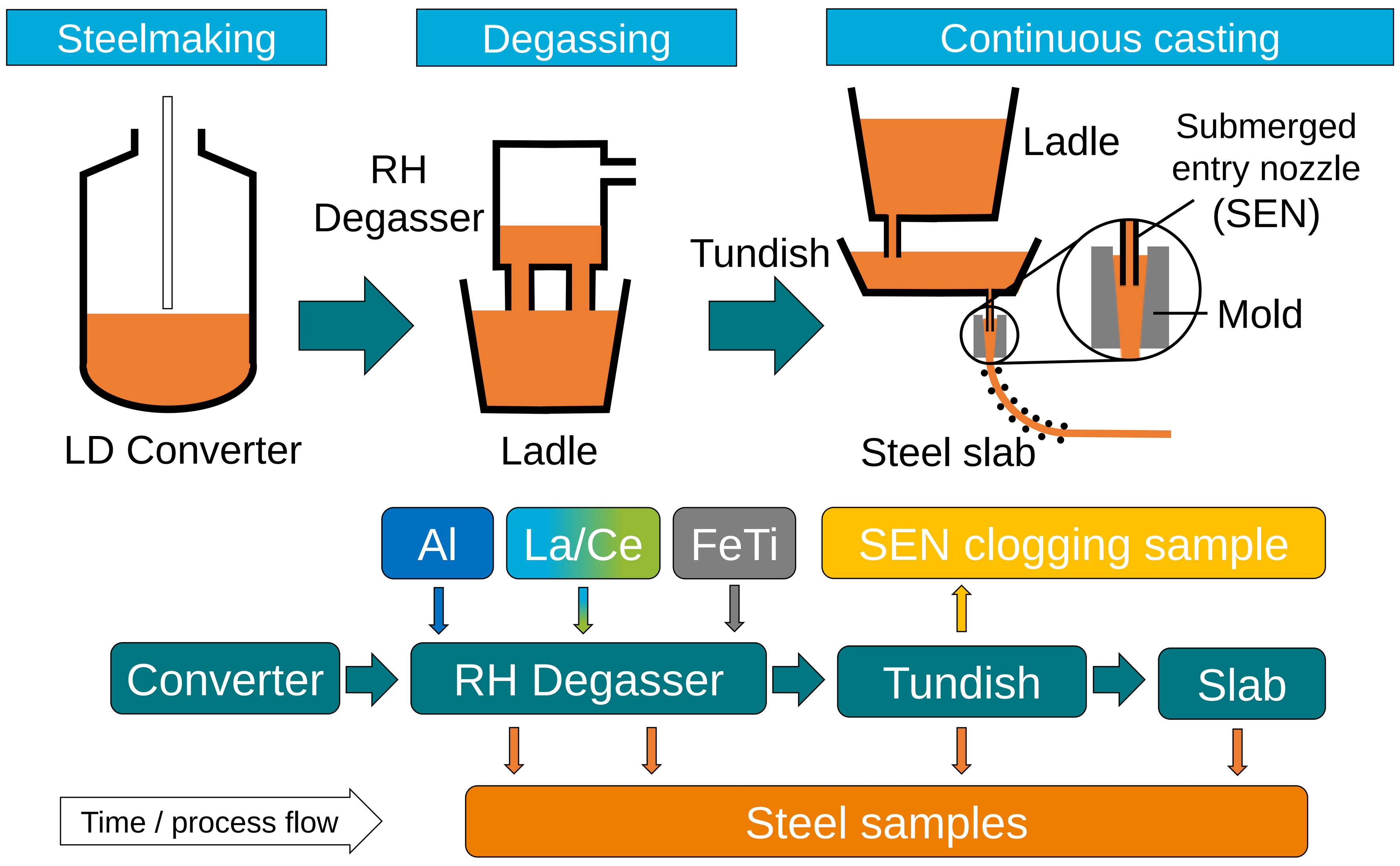

Fig. 5: *Schematic of the steel production process, Material flows and sampling strategy.*

Active tracing

In the active tracing approach, La and Ce are added to the steel melt on an industrial scale. [4] Due to their high oxygen affinity, these elements are quickly transferred into oxide phases, such as NMIs consisting mainly of Al oxide, following equation 1:

$$2\,Al_2O_3 + 2\,La \rightleftharpoons La_2O_3{\cdot}Al_2O_3 + 2\,Al \qquad (1)$$

Steel samples from two heats (using the same SEN) were analysed using ICP-MS (Fig. 6), heat 1 with La addition and heat 2 with Ce addition (~40 mg La/Ce per kg steel). The clogging layer formed at the SEN was investigated using SEM/EDS, as were individual NMIs found in the steel slabs (Fig. 7).

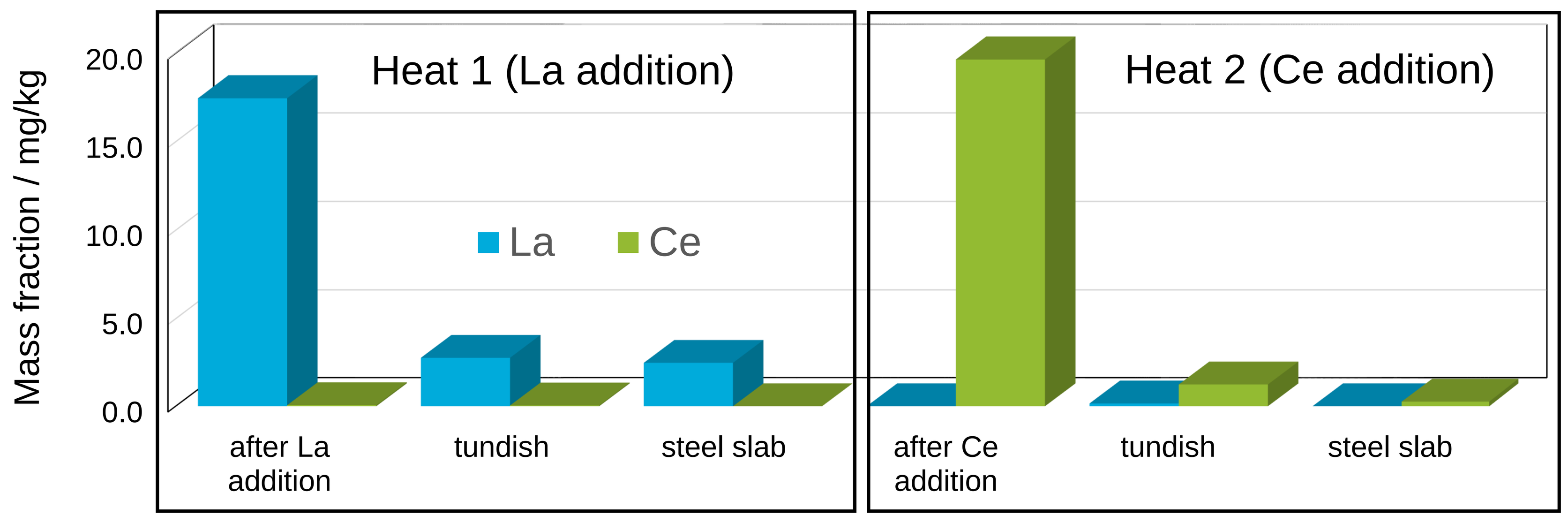

Fig. 6: *La and Ce mass fractions in steel samples taken throughout the process, determined using ICP-MS after acid digestion.*

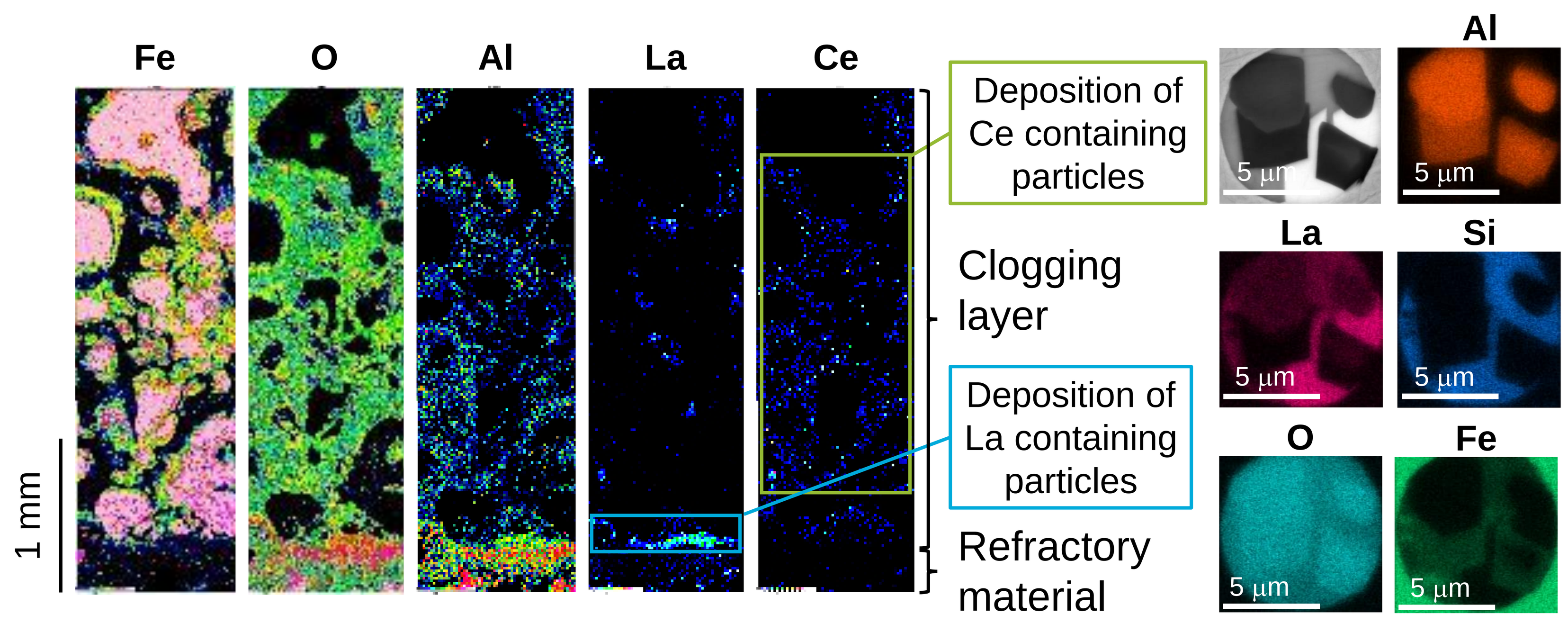

Fig. 7: *Left: SEM/EDS element mappings of the clogging layer deposited at the SEN*
Right: SEM/EDS image and elemental mappings of a La containing NMI

- La and Ce were found in in the SEN clogging layer, in individual NMIs in steel slabs, and in bulk analyses of steel samples (most likely also present in NMIs).
- There is only a short window of time in which REE are available for reactions as in equation 1, before they are oxidised and transferred into the slag phase.
- Therefore, the oxide material building up the clogging layer (and NMIs) must have already been present at the time of La/Ce addition, leaving Al_2O_3 generated from added Al as the most likely source.