Formation and modification of non-metallic inclusions through slags during ladle treatment

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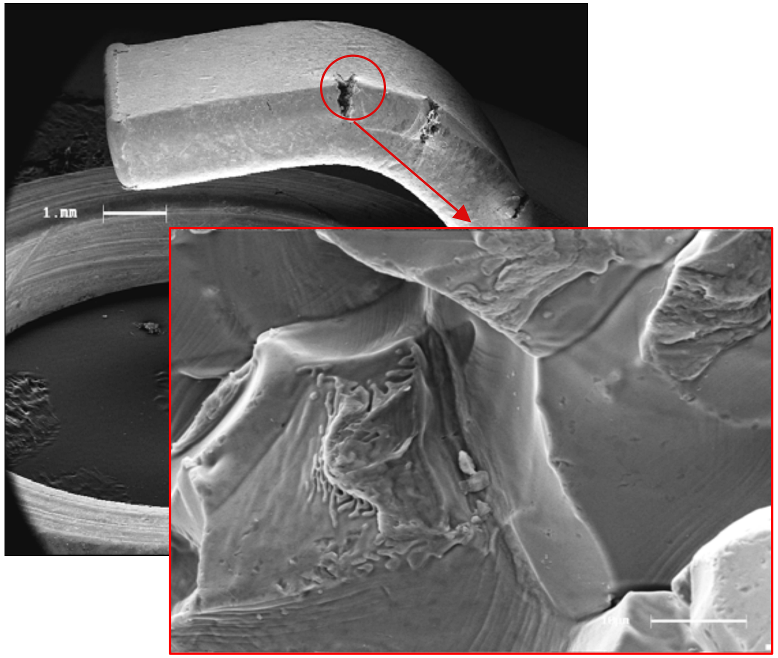
Aim of investigations

- non-metallic inclusions (e.g. alumina, MgO-alumina-spinel) harmful in steels
- complete removal during not possible
  - ➢ effect of ladle slag on inclusions?
  - ➢ modification to less harmful inclusions possible?
  - ➢ low-melting inclusions?



- reoxidation through ladle slag (e.g. FeO, MnO, SiO_2)
- formation of new inclusions
- loss of alloy elements (e.g. Al, Ti)
  - ➢ slag with low reoxidation potential?

➢ optimized ladle treatment strategies for steelmaking industry

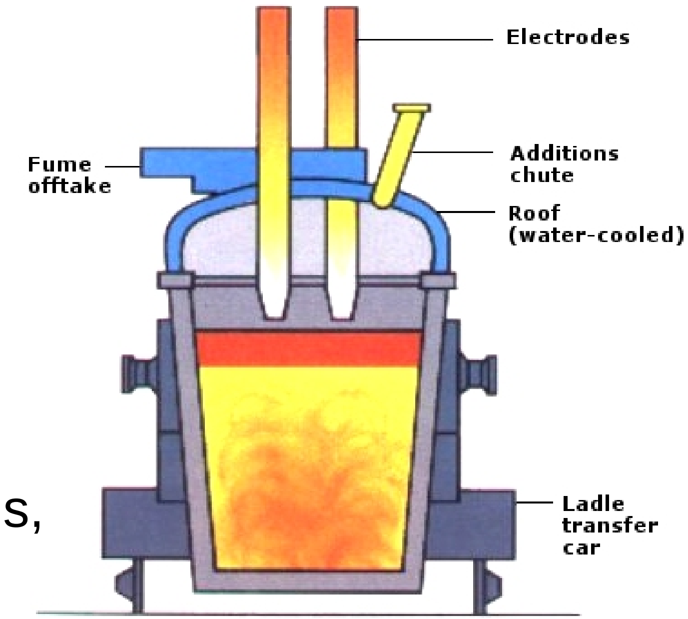
➢ approximate industrial practice and analyze potentials

Basic modeling data

- ladle treatment during secondary steelmaking:

  deoxidation, alloying, stirring
- equilibrium between steel melt, slag phase, non-metallic inclusions in steel

  → complex equilibria
- modeling with FactSage using data:
  - steel and slag compositions, alloy additions, temperature
  - FACT-databases
  - preselection of solution (steel, slag, complex inclusions) and compound (pure inclusions) phases
- time-dependent behaviour through kinetic approximation
- usage of macro language and Microsoft Excel



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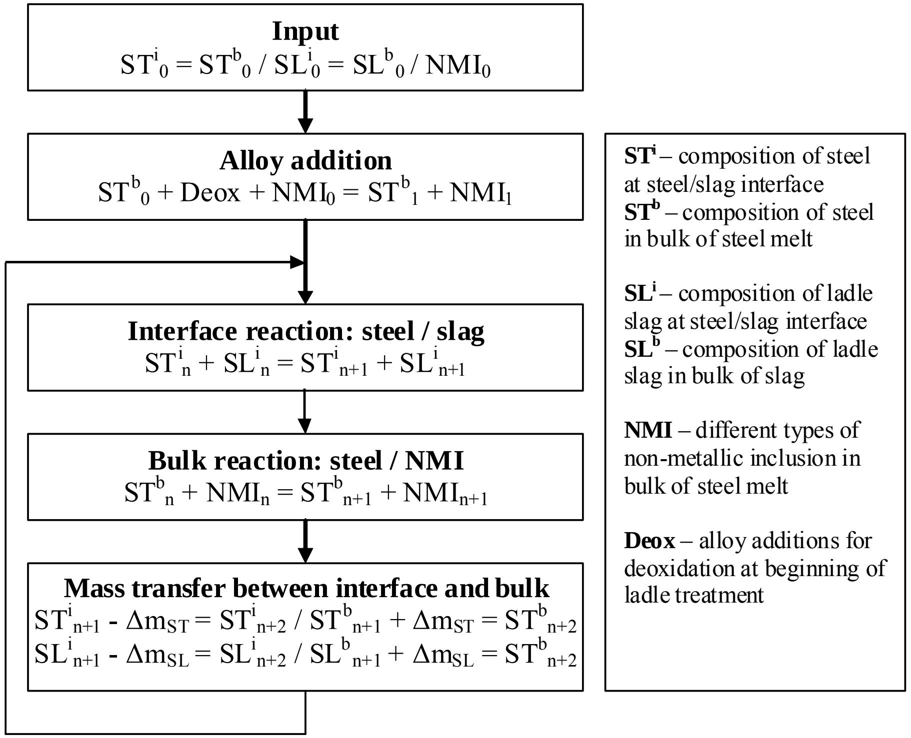
Model development

- no overall thermodynamic equilibrium possible
  → reactions only at interfaces
- splitting into two reaction zones
- consecutive equilibrium calculation
- mass transfer according to concentration gradient (diffusion) and stirring (mixing)



Bulk equilibrium: steel melt / non-metallic inclusions

Interface equilibrium: steel interface / slag interface

Example - alloyed tool steel

- modeling Al-killed tool steel in secondary steelmaking
- start steel composition [wt%]:

C	Mn	Si	Cr	Ni	Mo	V	Al	heat size
0.4	0.4	1.0	5.3	0.1	1.3	0.9	0.1**	65 t

*[O] assumed to be 0.06 wt% after tapping

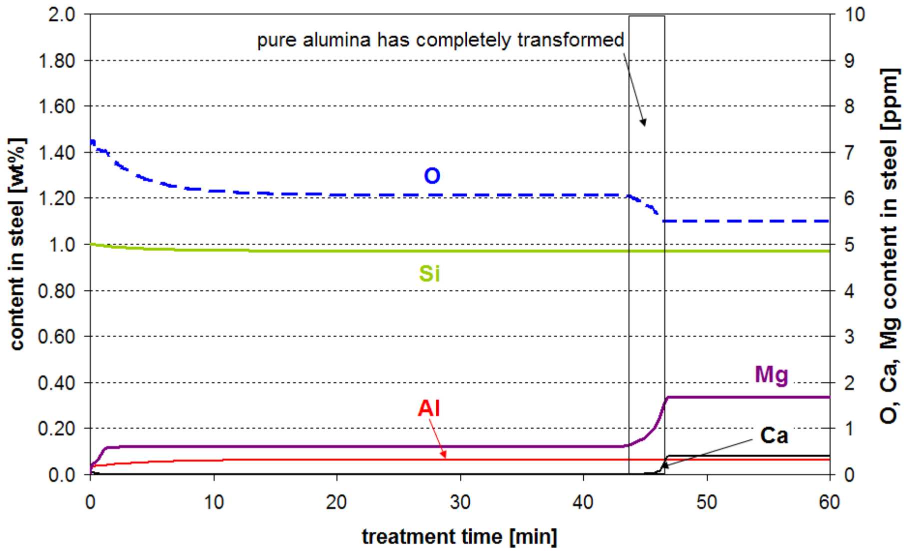
** Al added immediately after tapping

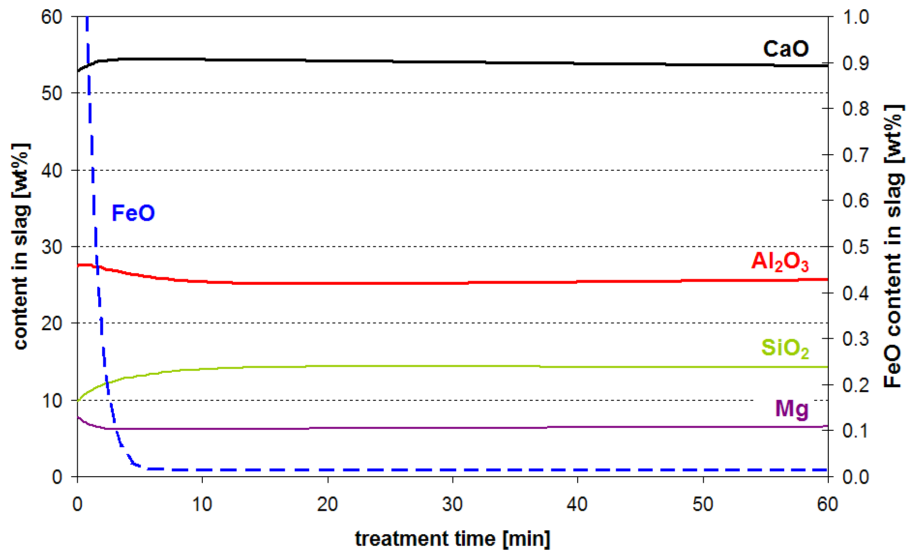
- variation of slag composition [wt%]:

CaO	SiO_2	Al_2O_3	MgO	FeO	MnO	slag amount
54 (± 8)	11 (± 5)	26 (± 6)	9 (± 4)	0 (+2, +4)	0 (+2, +4)	1 t

Steel and slag chemistry variation

- time-dependent change of:
  - steel composition
  - slag composition
  - type and amount of non-metallic inclusions
- formation of alumina at start
- introduction of Ca, Mg from slag
- loss of silicon
- recovery of aluminum
- steady transformation of alumina into spinel-type and calcium-aluminate inclusions
- decrease of oxygen content





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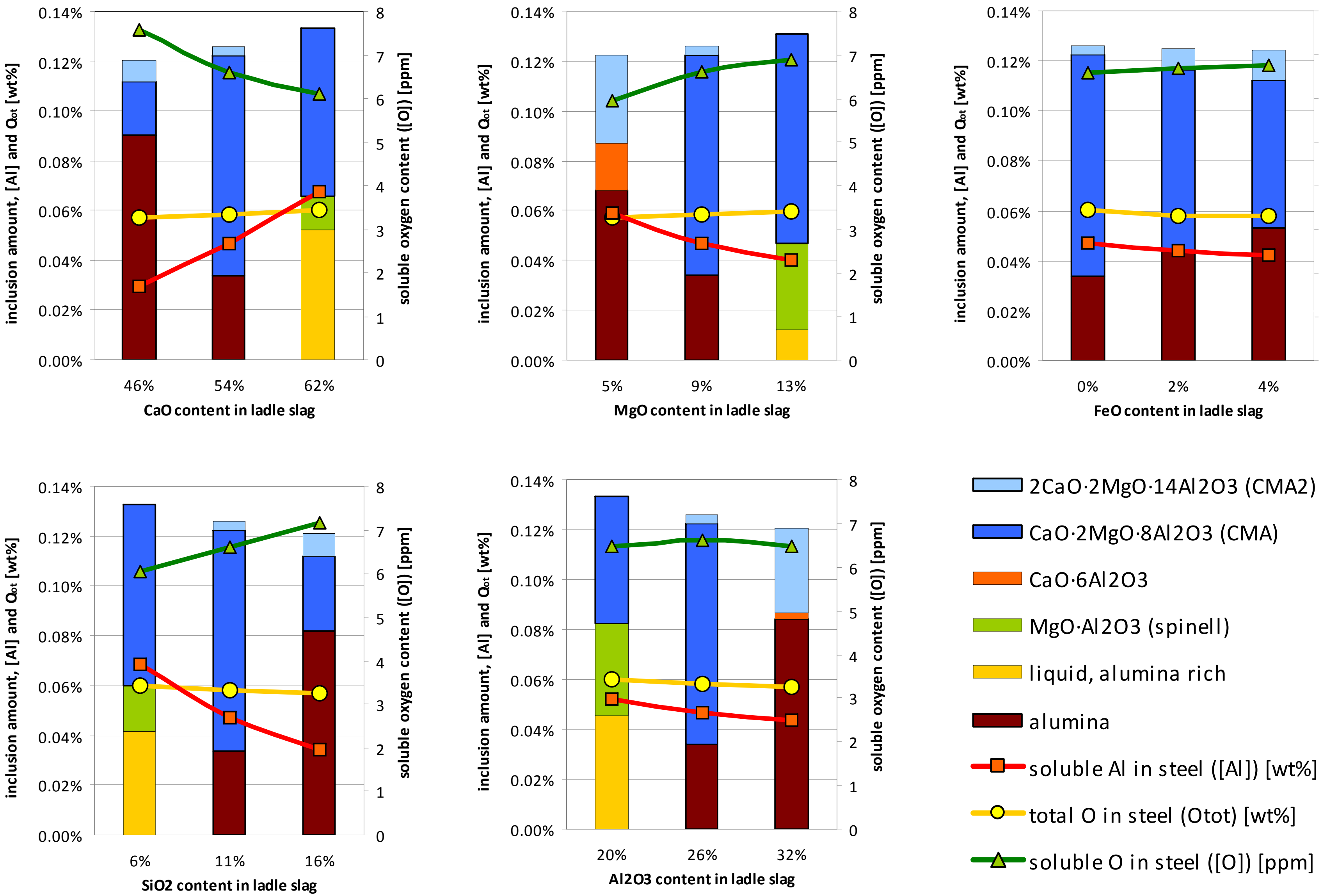
Effect of ladle slag on inclusion types



- results after 60 min of ladle treatment / only variation of ladle slag

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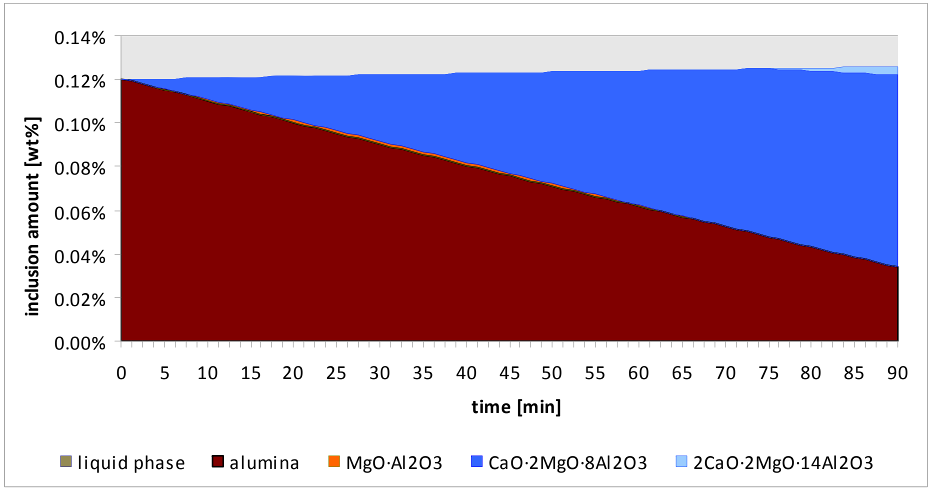
Main conclusions

- pure alumina only stable at low CaO content of slag
- liquid inclusions only at very high slag basicities (CaO/SiO_2)
- pure MgO-alumina spinels only at high MgO contents

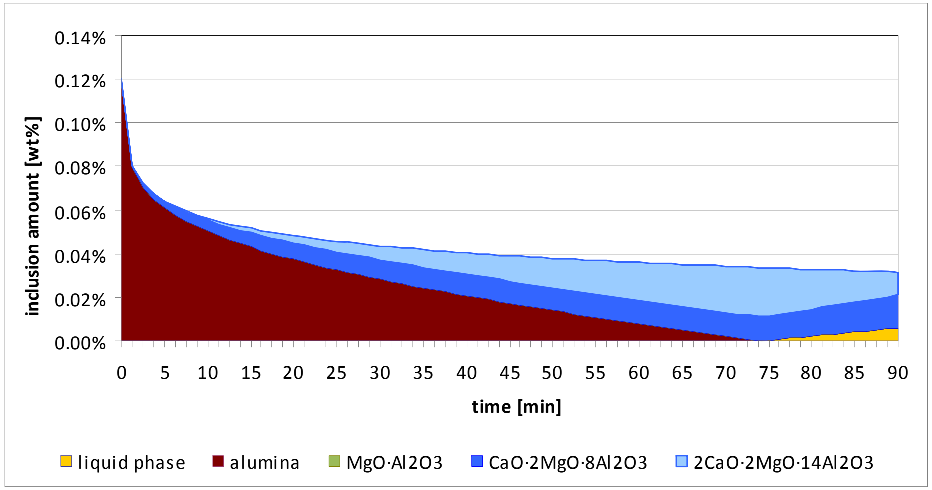
- total oxygen content (amount of inclusions) hardly changeable
- aluminum losses increase strongly with SiO_2 content
- low aluminum losses with liquid inclusions (low activities of components)
- small effect of FeO content at low level

Other effects

- modeling of inclusion settling
  - ➢ continuous addition to slag interface
  - ➢ remaining inclusions transform faster



- variation of start steel composition
  - ➢ modeling of variation of furnace operation



- variation of alloy addition
  - ➢ modeling of variation of alloy composition and tramp elements

Future work

- comparison of model results with laboratory and practice experiments
  - ➢ inclusion types at certain times, steel composition

- including ladle refractory interaction
  - ➢ new reaction zone: steel melt / ladle refractory

- coupling of thermodynamic calculations with fluid flow modeling
  - ➢ calculation of equilibria in several parts of the ladle
  - ➢ introduction of mixing through fluid flow (steel and slag)

Thank you for your attention!