DissTec

Valorisation and dissemination of technologies for measurement, modelling and control in secondary metallurgy

Enhanced steel ladle life and thermal state ladle monitoring by temperature measurements and numerical simulation of temperature and stresses

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Stahl

Selected RFCS research projects dealing with aspects of steel ladle refractory and thermal state

Contract Report	Title	Participants	Date Start / End	Topic regarding
RFSR-CT-2009-00003	Enhanced steel ladle life by improving the resistance of lining to thermal, thermo-mechanical and thermo-chemical alteration (**LadLife**)	Sidenor, CSM, BFI, Lucchini	01.07.2009 to 30.06.2012	ladle refractory life
RFSR-CT-2014-00006	Improving steelmaking processes by enhancing thermal state ladle management (**LadTherm**)	BFI, AMB, Sidenor, KTH	01.07.2014 to 31.12.2017	ladle thermal state

Ladle refractory – Introduction

- Ladle refractory wear is an important concern for steelmakers:
  - for economic aspects,
  - for the influence that ladle lining condition has on productivity and quality of the steel
- Ladle breakthrough due to premature wear of the working lining can happen if lining is not properly operated (e.g. during preheating), representing a severe risk

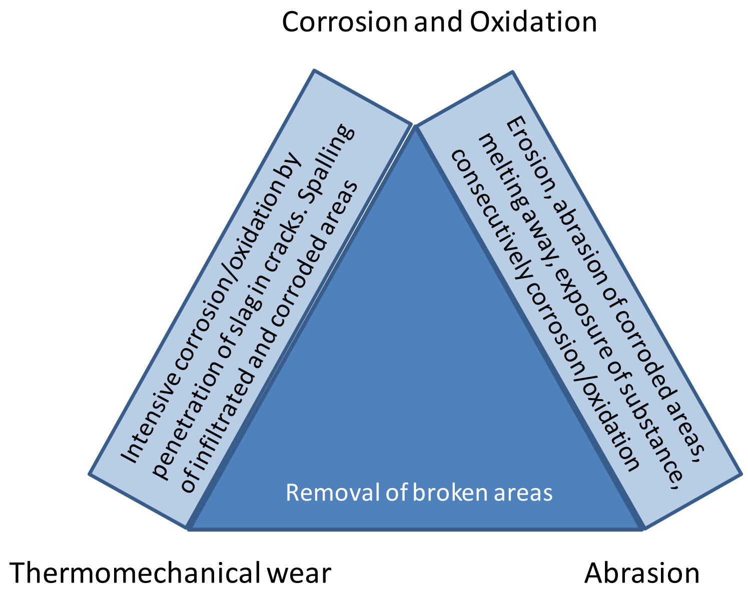
→ Ladle life must be predictable and reproducible, for safety and smooth processes

- Usual approach:
  - Inspect the ladle lining condition after some heats
  - Retire temporally the ladle from its normal use to cool down for inspection

→ If the lining is in good condition additional energy is needed to reheat the ladle and the normal plant operation would have been disturbed unnecessarily, with an impact on the productivity of the plant

Ladle lining wear I

› … is the consequence of thermal, physical and chemical stresses on the refractory



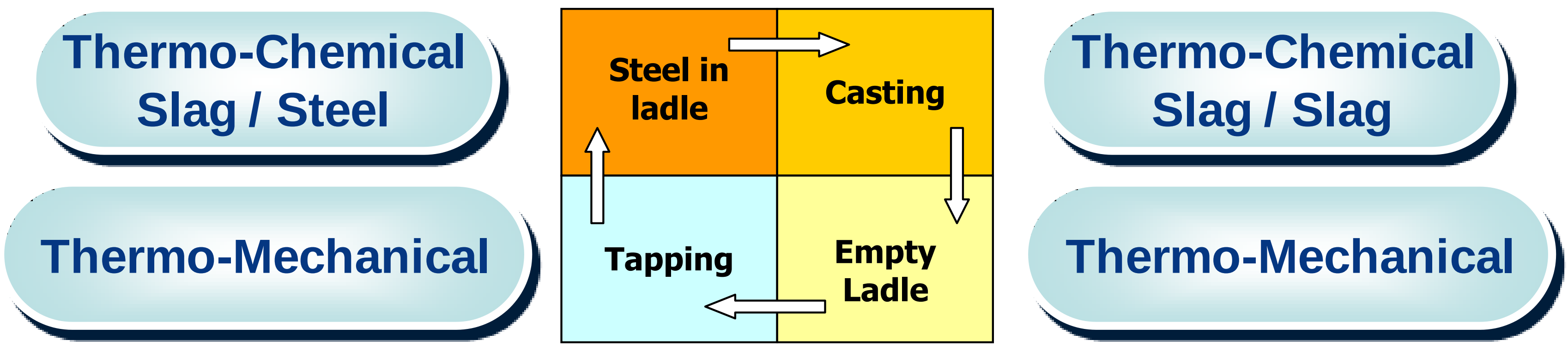
After: H. Jansen: Feuerfestverschleiß durch Thermomechanik und Abrasion in Stahlerzeugungsprozessen. stahl und eisen 125 (2005) Nr. 11, p. 43-48

› These stresses
  › activate modifications inside the oxide systems, and
  › cause alteration of their original structure and composition.
  › depend on the process conditions

→ The duration of ladle lining depends on the resistance of the oxide system to the degradation phenomena activated by the process

Ladle lining wear II

- Working life of steelmaking ladles is cyclic, with different mechanisms of attack and degradations active during each stage:



- Physical and chemical alteration of ladle lining cyclic
  - → The effect at each step depends not only on the process conditions present at the moment, but also is influenced by the state of the refractory derived from previous stages

Project LadLife: Enhanced steel ladle life by improving the resistance of lining to thermal, thermo-mechanical and thermo-chemical alteration

Main objective:

- to prolong the working life of ladle refractory lining

First partial objective: Model development

- Tracking of ladles during their working life, collecting process data and samples
- Thermo-mechanical investigation of collected materials (in laboratory)
- Simulation of processes suffered by the sampled refractories

Second partial objective: Implementation

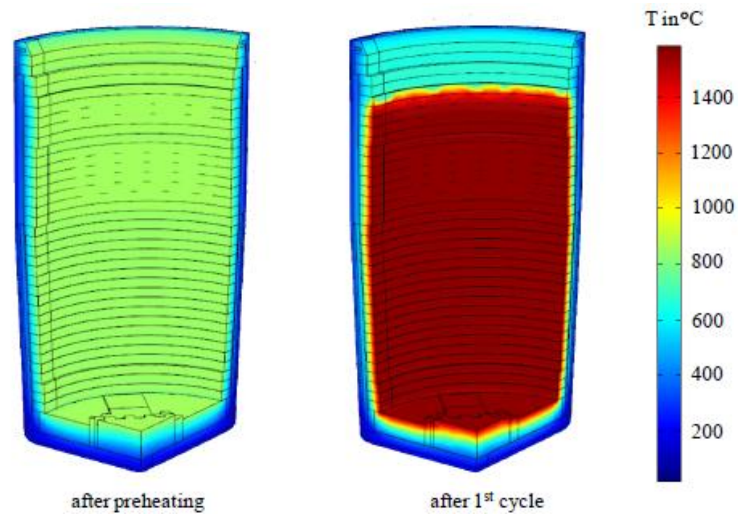
- Definition and application of process rules and optimum materials for operation
- Implementation of a soft sensor for ladle lining condition
- Assessment of economical benefits achieved with optimized materials and practices

RFCS project LadLife – Approach for FEM modelling

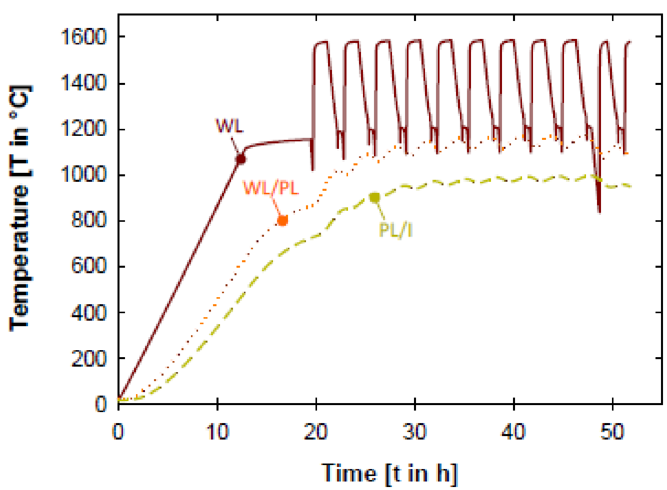
1. Collect data:
› Process data (e.g. heating times, steel temperature)
› Material data (if possible temperature-dependent, e.g. density, thermal conductivity)
2. Set-up numerical model:
› Set-up of geometry (1D, 2D, 2D rotationally symmetric, 3D)
› Definition of conditions (e.g. boundary conditions)
› Meshing
3. Calculate actual state
4. if possible: Validate model = correlate to industrial data (e.g. temperature measurements in ladle lining or steel shell)
5. Calculate different scenarios

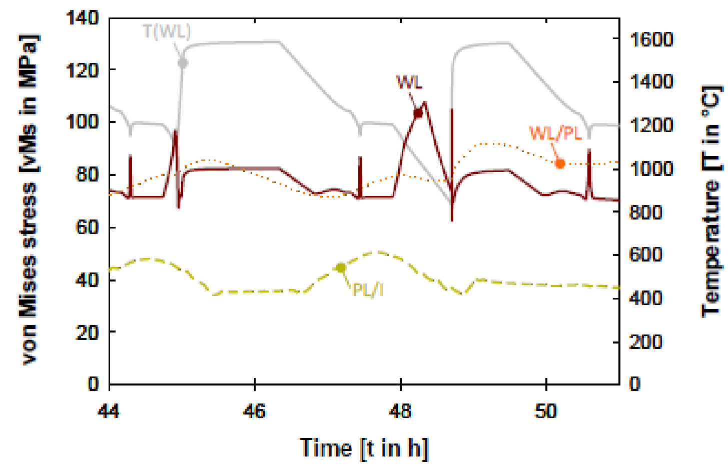
RFCS project LadLife – Results FEM modelling I

- Three ladles simulated
- Several different cycles simulated
- Different ladle configurations simulated



Temperature distribution in ladle II

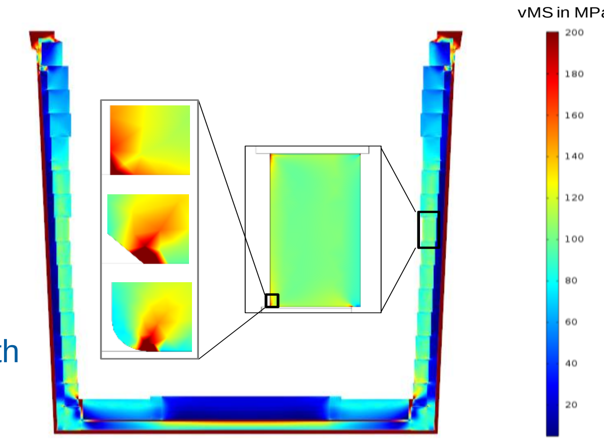




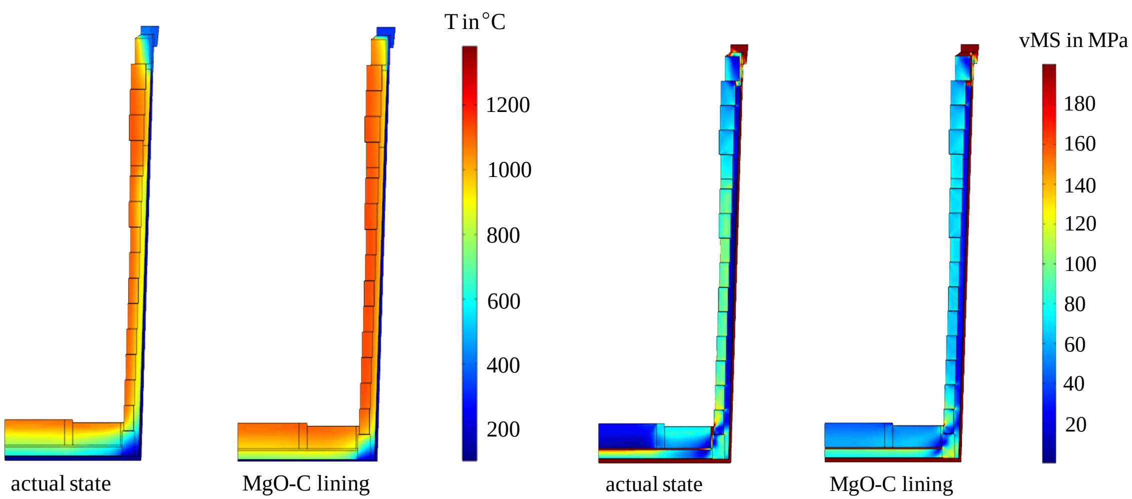
Temperature and stress profiles during first 10 cycles including initial preheating and a tapping delay after 9th heat at different positions in ladle III

RFCS project LadLife – Results FEM modelling II

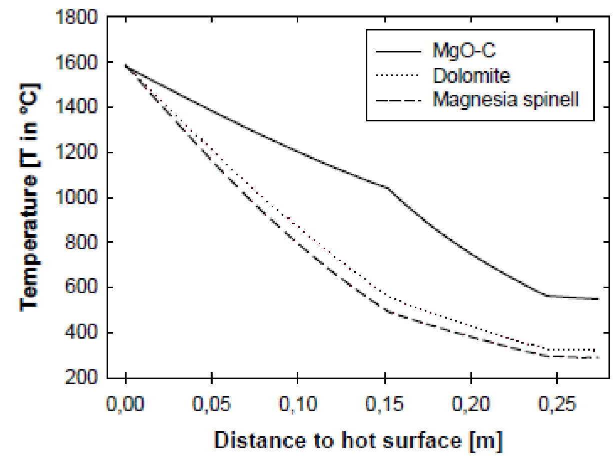
- Different materials simulated
- Brick wear simulated
- Round corners simulated
- For all the cases thermal and stress fields obtained



Von Mises stress distribution in one brick with different corner geometries after preheating: unchanged, sloped and rounded (ladle III)



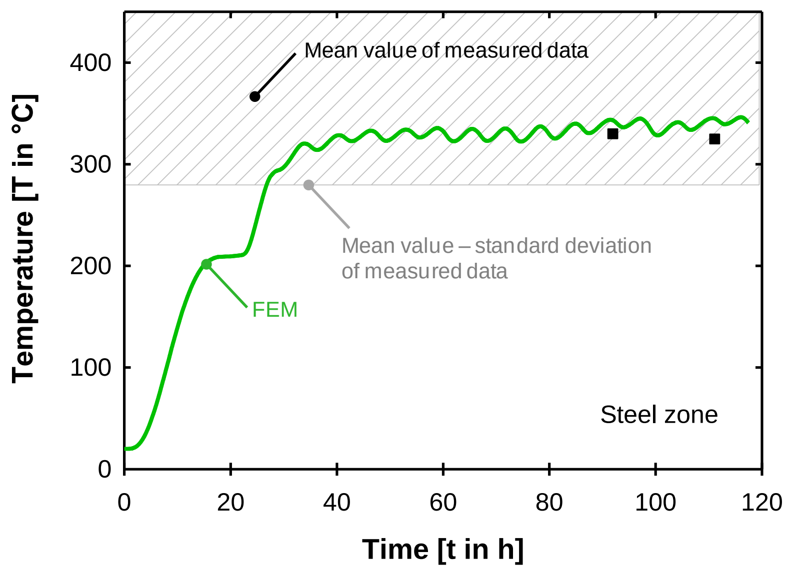
Temperature and von Mises stress distribution in ladle III with different working linings after preheating

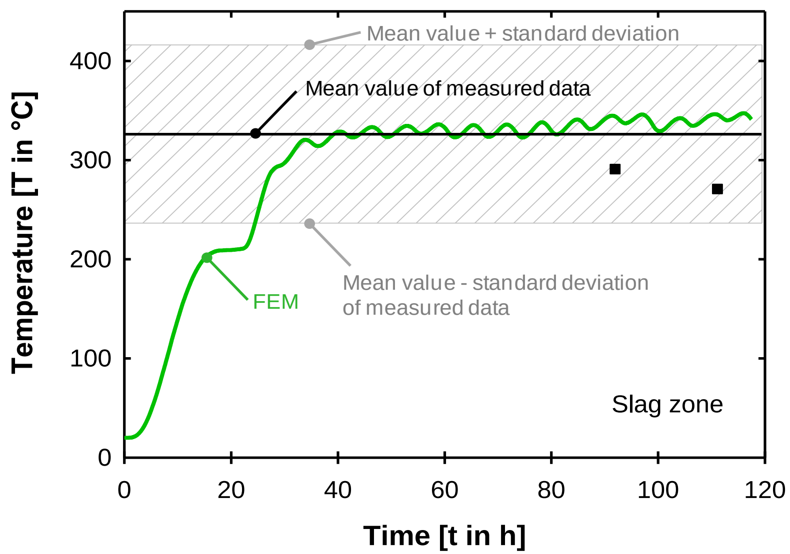


Temperature over ladle wall (ladle II) with different working lining materials

RFCS project LadLife – Results FEM modelling III

- Thermal models checked with production data
- Thermo-mechanical results checked with industrial performance
- Most conclusions were supported by data (temperature measurements) and experiences (thermal steady state)





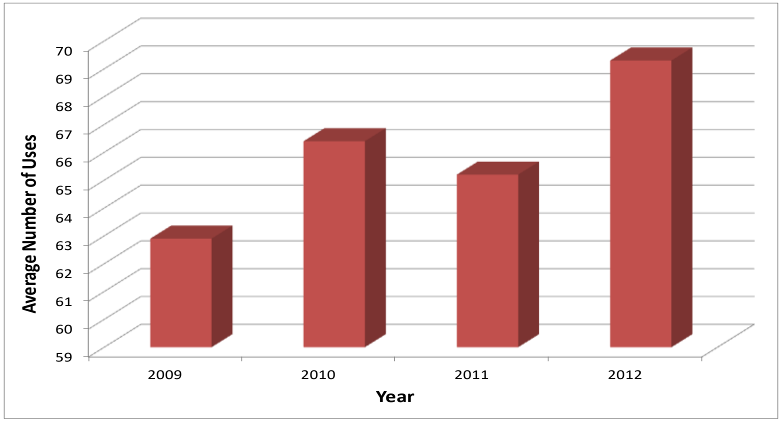
Comparison of outer steel shell temperature calculated from FEM simulation to measured data at steel and slag zone

RFCS project LadLife – Conclusions FEM

- Thermo-mechanical studies using FEM have proved their value to check different refractory as well as operational configurations and give advice about them.
- Analysing operational practices FEM simulation was able to show the effects of delays in production plan. Cooling down below 1000 °C is critical.
- Differences between MgO-C and resin-bonded dolomite bricks were checked. Less thermomechanical stresses are expected for MgO-C bricks but they will lead to higher steel shell temperatures as long as the other geometry remains unchanged.

RFCS project LadLife – Industrial benefits

- Positive objectives achieved at industrial partners:
  - Individual refractory products of superior technological characteristics applied, that have increased the number of heats per campaign
  - Improvement of ladle refractory life added to other improvements as ladle capacity and security



- Optimizing refractory wear rates results in less material consumptions.
- Increased amount of liquid steel in ladle improves operational costs.
- The reliability of steelmaking processes can be improved by better understanding and monitoring. That leads to increased productivity and safety.
- Optimized scheduling of maintenance operations result in reduced costs.

Ladle thermal state – Introduction

- Strict liquid steel temperature control from tapping throughout secondary metallurgy is needed for successful casting of high quality products
- Otherwise, severe disturbances of steelmaking or casting processes may occur and the quality of the final product might be reduced.
- Continuous measurement of the steel temperature in the ladle from tapping to casting is not possible

  → Liquid steel temperature is predicted by models and the steelmaking processes are adjusted accordingly
- One important factor: heat stored in the refractory lining of the steelmaking ladles
- Heat content of the refractories depends on the history of the ladles, with
  - heat transferred mainly from the liquid steel or from reheating burners into the ladle refractory, and
  - heat lost from the refractory into the atmosphere by radiation while the ladle is casting or empty and waiting to be refilled

Ladle thermal state – Temperature measurements and models

- Temperature measurements of the ladle linings with thermocouples inserted into the refractory at positions with different distances to the ladle shell

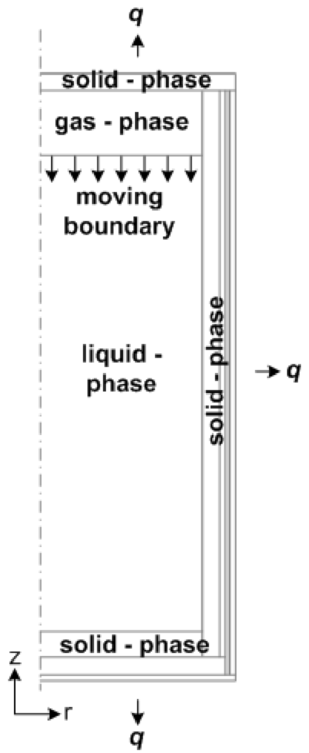
  - causes high effort in installation and operation

- Temperature of the inner ladle wall sometimes measured with a radiation pyrometer

  - unknown/changing emissivity coefficient for correct temperature measurement

- Results of mathematical modelling of the heat flow and heat losses through the lining are usually only once compared to the results of short-term temperature measurements for verification

  - the mathematical models are not based on the actual heat status of the ladle anymore
  → may calculate the ladle heat content incorrectly over time
  → with impact on all following calculations for the same ladle for all heats before relining of the ladle



Project LadTherm: Improving steelmaking processes by enhancing thermal state ladle management

Objectives:

- Monitoring the thermal state of steelmaking ladles during secondary steelmaking operations.
- Knowledge of actual thermal status of ladle will be used to improve existing liquid steel temperature models.
- Optimising the use of the thermal energy stored in ladle lining in order to
  - Decrease tapping temperature
  - Reduce ladle reheating durations
  - Better match the target casting temperature

Project LadTherm – Ways and means

Ways and means:

- Continuous measurement of ladle lining temperature

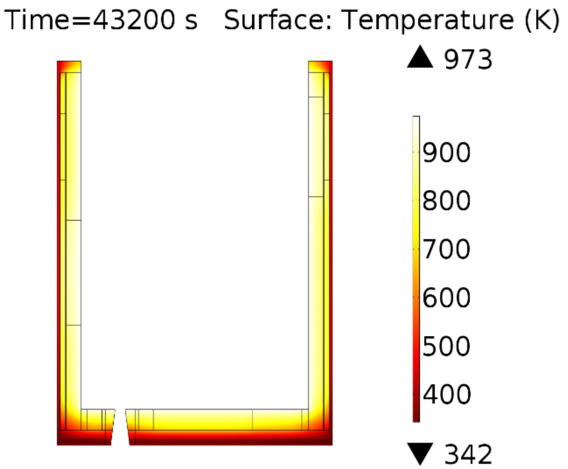
  → via wireless sensor or thermographic/pyrometric sensors

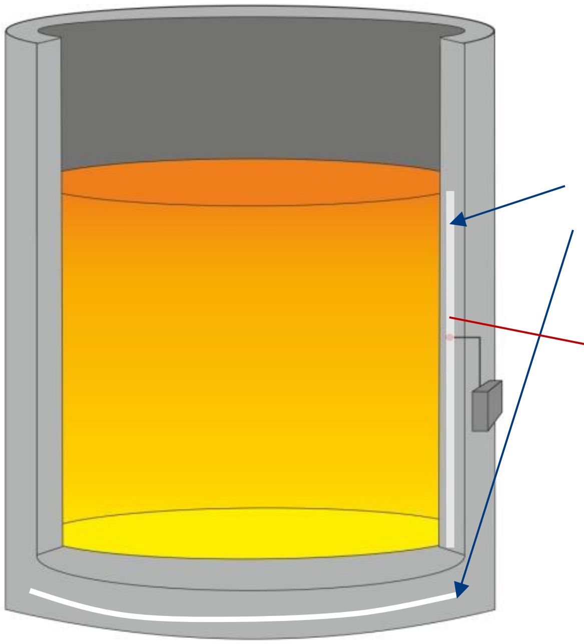
- Calculation of the actual total ladle heat content Q that is stored in the ladle lining using thermal models
- Introduction of Q as a new input parameter for ladle thermal state monitoring systems, steel temperature prediction models and advisory systems for best ladle practices

Project LadTherm – First results

› Temperature measurement in ladle lining using thermocouples and FEM model used to define optimum position for sensor

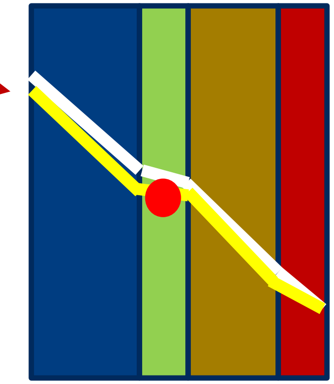
› Online model developed that will be adapted during steelmaking process by using measured temperatures





Two steps:

1. Use the above relationships to make correction at the same $R_{measure}$. Make correction similarly for bottom
2. Recalculate the T through the thickness



Overall conclusions and benefits

- Refractory wear and thermal state of ladle is of great interest for steel plants
- Challenges regarding wear are always actual due to changing refractory raw materials, process conditions, changing steel grades, …
- Combination of modelling and laboratory investigations as well as process data analysis creates improved knowledge on refractory/steel/slag systems
- FEM simulation enables:
  - Reliable and cost saving control of operational conditions and different scenarios
  - Layout and optimisation of refractory constructions
  - Adjustment between refractory lining and plant operations
  - Comparison of different refractory materials used in specific applications
    - Adjustment of MgO-C bricks resulted in increase of life time of up to 20 %
  - Knowledge and optimisation of thermal balance of vessels, especially in combination with temperature measurement

- Increase of life time of refractory lining of metallurgical plants and therefore enhanced durability
- Higher productivity
- Lower maintenance costs

Thank you very much for your attention !

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