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Smart consideration of actual ladle status monitored by novel sensors for secondary metallurgy process parameters and ladle maintenance strategies

SmartLadle

Public

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Deliverable 4.2 – Preparation and execution of industrial trials

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Project summary

What is the effect of the actual ladle status -new to worn- on steel bath properties? How do e.g. temperature or fluid flow vary with ladle conditions? When is the optimal moment for relining?

SmartLadle will provide a solution for online monitoring and dynamic incorporation of actual ladle status for process control. A soft sensor for ladle status shall be developed, supported by a smart sensor for detecting refractory wear and thermal status. Measurement data, models and advisory tools shall provide information for decision making to operators to adapt ladle metallurgy process parameters to actual ladle status and decide about maintenance actions.

Definition of terms used in the project

Soft sensor: Mathematical calculation of value of a process parameter that is difficult or so far impossible to measure directly and online, based on other process values, measurements, models and smart sensor data.

Smart sensor: Combination of a pure sensor for the acquisition of a measured value, e.g. refractory temperature, and a small computing unit with implemented simplified models, e.g. for refractory wear.

ML model: Data-driven model that analysis data and detects relationships (linear or non-linear) among variables based on real-world data using Machine Learning (ML) Techniques.

1. Introduction

Deliverable 4.2 describes parts of the work performed in Tasks 4.2, 4.2 and 4.4 and provides summarised information about the objectives and performance of industrial trials at the three steel plants.

The performance of plant trials should be realised to:

- test the sensor applications in steel plant,
- evaluate the performance of different refractory materials and operational process parameters, e.g. stirring parameters and slag conditioning,
- provide relevant data for establishing rules for the Advisory Tool in WP5.

For SWG, this covers a trial to be performed with optimised ladle refractory lining concept based on FEM simulations carried out by BFI.

For UAB, this covers planning of industrial trials over a ladle cycle and carrying out additional measurements to add more information for calibration of the soft sensor.

For Swerim, the work package involves developing a soft sensor using results from CFD modelling and smart sensors. Continuous improvement of the soft sensor will be carried out based on UAB trial data for establishing basic rules and models for an Advisory Tool.

For SID, this covers:

- Tundish related trials for liquid steel temperature calculation and
- Ladle related trials including slag analysis, thermal shocked ladles and ladles with different configuration.

2. Adaption of ladle refractory and/or ladle practices (BFI, SWG)

This work included the definition and adaption of optimised refractory lining concept and/or ladle practices based on the results of the FEM modelling performed in WP3.

Before calculating different scenarios using the FEM model from WP3, BFI and SWG discussed the aim of such an optimised concept and possible improvements that could be beneficial for SWG steel plant. During this discussion it became clear, that changing ladle practices would not work at SWG due to restrictions in the production schedules and rather less flexibility in this aspect. Instead, the focus of the optimised refractory concept should be on two aspects:

Focus of optimised refractory concept	Aim of the optimisation
Changed refractory material with different thermal conductivity than those currently used	Decreased heat losses of the ladle → resulting in higher steel temperature at casting and thus decreased energy needed for heating the liquid steel in LF
Different geometry of refractory layers (thicker lining, variable thickness over ladle height)	Increased ladle life → resulting in less maintenance effort

SWG will adapt one ladle with an optimised refractory lining design. The optimised ladle layout will be chosen based on calculation of different scenarios using the FEM model developed by BFI.

Ladle lining and test of ladle with different refractory material will depend on

- The time when the FEM results are available, and
- The delivery times of the materials (up to 12 weeks).

3. Design and definition of strategies for steel grades and/or process conditions (SWERIM, UAB)

UAB will carry out trials at the melting shop covering all stages in a ladle cycle and using new measurements to fine-tune the soft sensor provided by Swerim based on CFD results. The soft sensor and CFD takes into consideration the ladle history in terms of hours with melt in ladle, hours with vacuum treatment in ladle, ladle tare weight, heat weight, and other dynamic process data.
During the trials, additional measurements will be made such as: measurement of slag thickness, measurement of refractory at the end of ladle life and vibration measurements for fine-tuning of the CFD model. Similar process data will be available as were for the trials carried out in the autumn of 2022, however no laser measurements will be made of the ladle lining at this time.

4. Specific industrial trials to check concrete aspects towards model optimization (SID)

In WP2 the basis of monitoring tundish refractory temperature with thermocouples were established, but further measurements were needed to assess the thermal behaviour in a more general way. Thus tundish trials in WP4 consisted of:

- More trials with new tundishes were done to increase the data available (see Figure 1).
- Thermocouples were able to survive for long time.

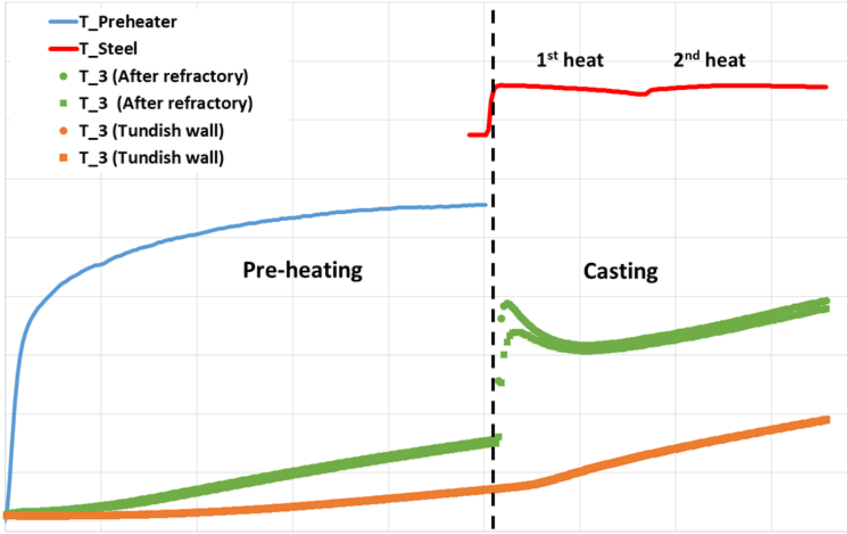

Figure 1: A new example of successful trial in tundish refractory temperature, including pre-heating and a 2 heat sequence

Further work related to those trials was to test systems to transmit the temperature signal wirelessly and in an unattended way. This improvement and the learnings to protect the thermocouples make it possible to get long term results, concretely:

- Two options for wireless data transfer were checked: Using open hardware and using a commercial system (see Figure 2).
- Some data obtained successfully (Figure 3) although wireless transmitter suffered some heat related issues.

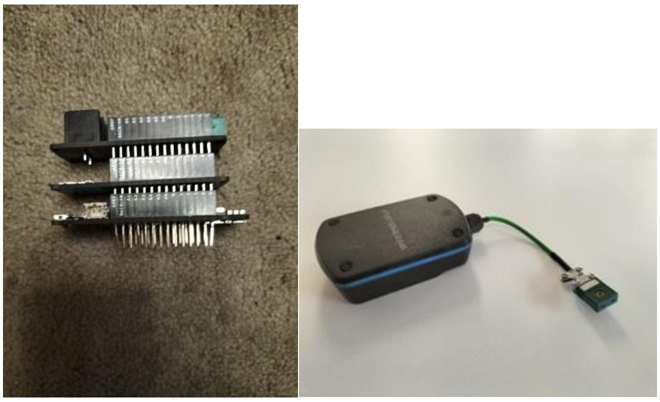

Figure 2: Analysed wireless systems to measure temperature from thermocouples and transmit temperature data

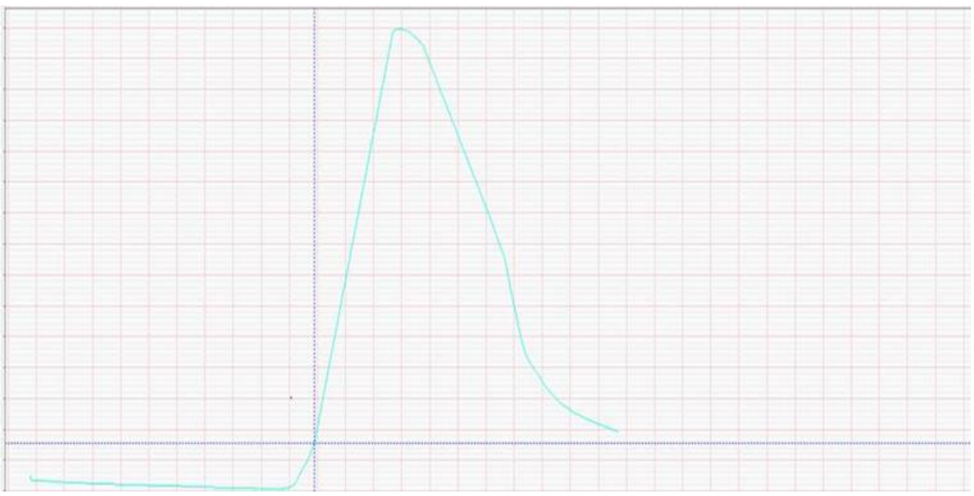

Figure 3: An exemplary temperature curve measured online

Additionally to those tundish trials, ladle trials were performed as helper trials for the different aspects of the advisory system for liquid steel temperature. They included checking the following effects on refractory wear:

- Ladle slag,
- Thermal shock,
- Specific steel grades

The procedure, objective, result and explanation are described below for each kind of ladle trial.

Ladle trials: Slag trials.

- Procedure: Slag samples taken from the same heat at different moments to assess MgO % evolution. (50 samples considered)
- Objective: Check the possible material flux from the refractory (MgO-C).
- Result: No clear effect was found (Figure 4).
- Explanation: Most MgO goes into slag at the beginning of secondary metallurgy.

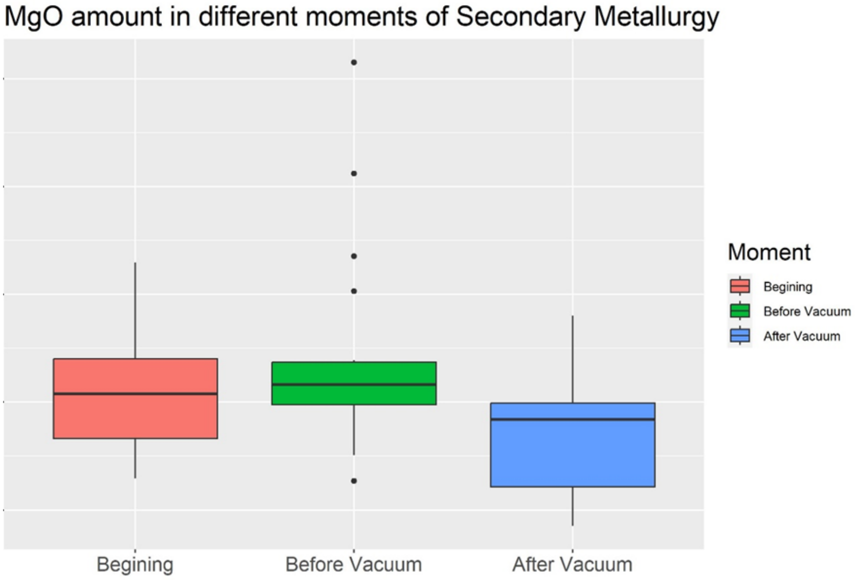

Figure 4: Ladle trials about slag: Compositions were measured in different moments of the process to check MgO evolution and, consequently, refractory wear

Ladle trials: Thermal Shock.

- Procedure: Count long stops (12h or 24h) in ladle life history and compare the effect over overall ladle life. (1 year data considered)
- Objective: Check the detrimental effect over the refractory.
- Result: No clear effect was found (Figure 5).
- Explanation: Number of stops per ladle similar, other factors more influential

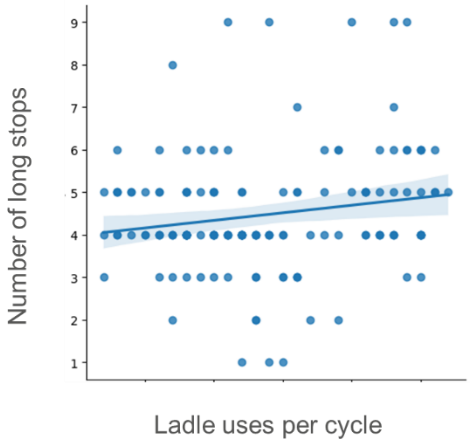

Figure 5: Ladle trials about thermal shock: Looking for the effect of long stops

Ladle trials: Specific steel grades.

- Procedure: Count number of different steel grade heats (stainless for example) in ladle life history and compare the effect over overall ladle life. (1 year data considered)
- Objective: Check the detrimental effect over the refractory.
- Result: Clear effect was found (Figure 6).
- Explanation: Those heats have a quantifiable detrimental effect.

These data help quantify the effect.

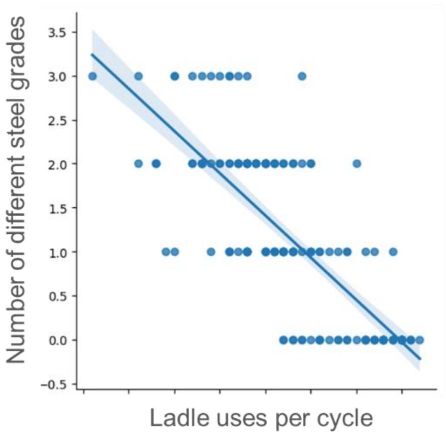

Figure 6: Ladle trials about specific steel grades: Check the detrimental effect over the re-fractory

Ladle trials: Specific steel grades.

- Procedure: Use some slightly different MgO material in specific ladles and ladle posi-tions and compare the effect with standard ladles
- Objective: Check the detrimental/beneficital effect over the refractory.
- Result: No effect was found.
- Explanation: The MgO bricks used were not so different to get a clear signal.

5. Summary and next steps

The trial at SWG focuses on the optimisation of the ladle regarding heat losses and/or increased ladle life. The results are not directly relevant for the subsequent work in the project regarding smart sensor and soft sensor.

The results from the UAB trials will be used to develop basic rules and models to apply in the Advisory Tool, such as recommended stirring practice for individual heats based on factors as steel grade, ladle life and estimated brick thickness/temperature.

Tundish trials with further refractory temperature measurements in SID helped obtain data to characterize tundish thermal behaviour.

Ladle trials in SID helped quantify detrimental effect of some steel grades but did not show effect of the long stops or tested refractories. MgO goes to slag since the beginning of secondary metallurgy.

Next steps will be:

- UAB and SWG perform trials as described above.
- SID trials helped get data for soft sensor and model developments.
- Improve/complete the models with those data.
- The calculation procedures can be useful to obtain additional data if needed.