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Novel concepts for establishing expert support systems to investigate the defect occurring in metallurgical phases in the technology of ISD DUNAFERR Zrt.

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Abstract. Competition among steel companies is intense in order to retain customers and get/gain new ones. Economic operators are much more critical of their suppliers and of the quality of their products due to increasing quality requirements. In addition to quality improvement measures to meet quality demands, cost optimization measures pose a major challenge for manufacturers.
Complaints always require an overview of the manufacturing process of the particular product, as it is essential for product development and can highlight technological issues that can eliminate similar types of complaints (improve product quality).
The investigation of the complaints requires extensive professional experience. Deep theoretical knowledge of the technological process, practical experience and knowledge of the local circumstances are essential. This amount of knowledge is available to the experts in varying degrees, and therefore, in addition to examining the main parameters, the aspects of the investigation may vary considerably. By creating or expanding a unified knowledge base, certain parts of the investigation can be analyzed and automated in higher detail. With this solution, the burden on experts is reduced, uniform investigation becomes possible, and examination aspects can be classified. Further statistical analysis may even make it possible to filter out technological parameters that are critical for quality.
The system described below is primarily designed from a metallurgical point of view, but with the expansion of its knowledge base it is also possible to study additional technological phases.

1. Introduction

During industrial processes, like steelmaking process, many parameters influence the characteristics and quality of the product released. Such parameters are e.g. the mass, temperature, composition, for which the knowledge of technology, operational practice and conditions is essential [1, 2, 3, 4]. It is important to have the required knowledge of the operating principles of the measuring devices / samplers, the criteria of their usability, the difficulties associated with them due to the operating conditions, and the specificity arising from the place of sampling. The temperature and composition homogeneity of the sampled material can also significantly influence the relevance of the measurements.

In order to judge the main characteristics of the process, it is not enough to check whether certain parameters of the process are within certain range, but even complex analysis of several parameters is necessary.

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During the Dunaferr steelmaking process, first and foremost, chemical compliance and castability are the main viewpoints. Unfortunately, the pursuit of safety (e.g. warmer production, higher overheating) often increases the chances of downgrading / complaints of rolled products in later stages. For example, based on previous studies [5], the overheating [6] of the steel transferred from the converter to the casting machine was significantly related to the degree of downgrading of the rolled product.

In this article, using the experience gained so far, the most important factors of steel production / casting, which are of greater importance for quality and especially for subsequent complaints, are reviewed and summarized. It is very difficult to evaluate the technological parameters and the underlying processes, as well as the characteristics that influence the quality of the product by studying the raw data series. Therefore, in recent years, we have aimed to develop data analysis methods that provide a clear view of certain details of the manufacturing process, making it easier to detect possible manufacturing errors. The mechanism of the effect of each parameter on product quality is also analyzed.

2. Examining data

When analyzing the production parameters, their nature and their influencing factors must be given special attention, so that they can be used properly in the further analysis and the conclusions drawn in this way are also correct. The following is a summary of the principles of evaluating technological data that are necessary to reach valid conclusions.

2.1. Validity of the data

The first step in investigation is to verify the correctness of the data [7]. Due to human-, measurement–, data transmission (IT) errors, data may be available which is not justified by the manufacturing process. It requires special attention because it may indicate a technology error or it might even be correct data, if other related data are incorrect. It requires great expertise to judge correctly.

It is also important to know the methods of measuring instruments [8]. For example, a „lollypop sampler" used to take steel samples use vacuum to suck up the sample. The sampler used after blowing in the high oxygen content steel bath, an aluminium wire deoxidizes the steel to prevent gas formation, which generates a high aluminium content of about 4% during analysis. This aluminium value must be ignored because it cannot be a real value thermodynamically.

From an IT point of view, the text in the comment field of the database is a serious problem because it cannot be handled properly, but may contain important information. E.g. in case of bottom argon stirring, the operator indicates that the argon gas has not entered the ladle and therefore the measured data are not accurate.

2.2. Range checking

The second step is to check the data within the required range. Out of range parameters do not necessarily mean error. Often, they only occur because of unexpected parameters resulting from operating conditions. It also needs a great professional experience to judge the justification of differences and their impact.

Certain treatments are often applied based on several considerations, which must be taken into account when assessing their justification. For example, the duration and intensity (or amount) of argon stirring (bottom and top) primarily affects the homogeneity of the steel bath, but also plays a role in temperature control and inclusion removal. At high intensities, a free steel surface may be formed, which may lead to additional oxygen / nitrogen uptake and inclusion formation, requiring additional deoxidizing agent.

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2.3. Time course of the data

The third step is to evaluate the time course of the data, e.g. temperature, composition (steel, slag), dosing and order of ladle metallurgy treatments. The time course is very important for thermodynamic processes and because Dunaferr technology does not have heating possibilities outside of the converter. Incorrectly selected order may result in e.g. a critical steel temperature drop, inability of casting or reduction in the period (in critical cases skipping) of ladle treatments, which affect the purity of steel, due to the forced process acceleration.

2.3.1. Composition and temperature changes

The compositions should reflect technological steps as well as the downstream nature of the temperatures (no heating possible). The added deoxidizing agent should reduce the active oxygen level in the steel and the FeO content in the slag. If this is not the case, and no other technological intervention can justify it (e.g. due to strong argon stirring, the unprotected steel surface absorbs oxygen from the environment) then the quality of the samples can be questioned.

2.3.2. Technological steps of steelmaking

The sequential nature of the technological steps can determine, among other things, the efficiency of the alloying process, explain the reasons for the addition of a greater amount of deoxidizing agent, and, for example, unpredicted technological steps before blowing because of unexpected scrap condition / chemical composition, or unexpected ladle condition.

The large drop in temperature between measurements (due to the lack of heat transfer outside the converter) poses a technological risk. A ladle that is red-hot inside, but not hot in its total cross-section, can be deceptive. Experience has shown that the strongest cooling occurs under intense mixing (argon stirring) and, therefore, due to the potential of high cooling, its duration can be significantly reduced, which is detrimental to homogeneity and inclusion content.

A program depicting the technological steps of the steel production phases, which can be run from a browser, has been created to facilitate the investigation of complaints. The program displays the required diagrams by entering the heat number (Figure 1).

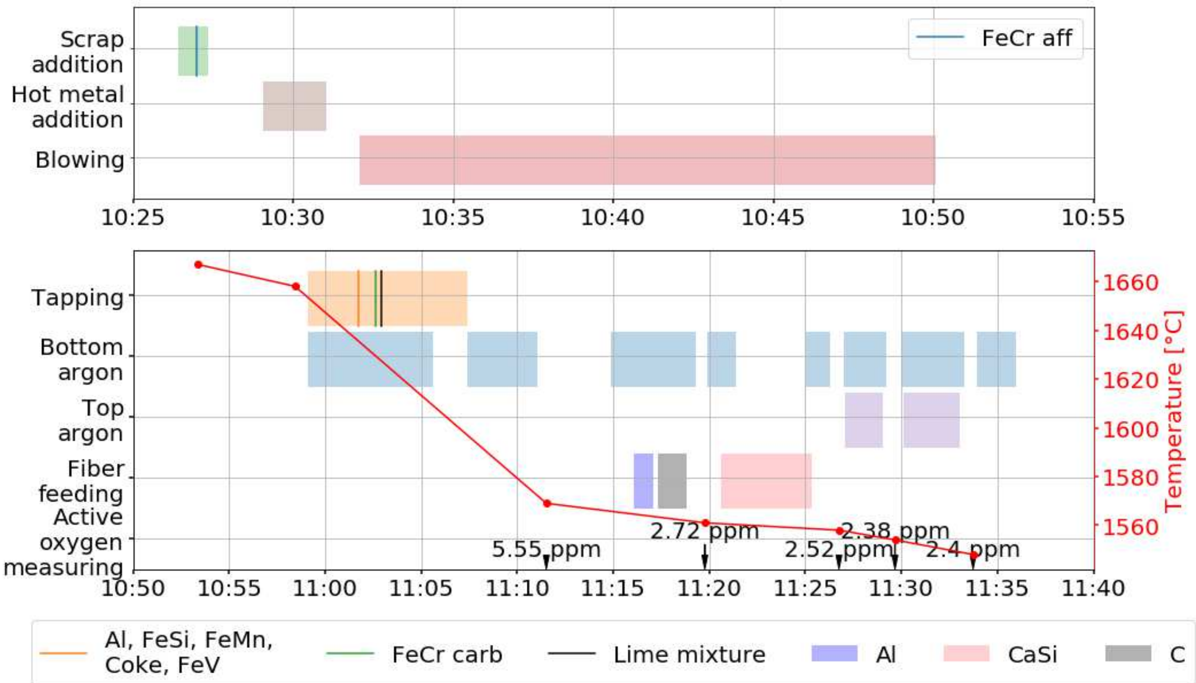

Figure 1. Time course of the technological process

The diagrams show the technological progress over time. It is also evident that the most intense cooling is caused by the addition of alloys and upper argon stirring. The charts also help to understand the followings:

- The deoxidizing agent used has been deoxidizing the steel or the slag.
    - In the case of the deoxidizing agent added to the slag, a large amount of primary slag flow was likely to be compensated in order not to oxidize the deoxidized steel.
- Order of alloys adding based on thermodynamic and technological aspects.
- Compensation of the sulphur or phosphorus content of the scrap by after blowing and slagging.

2.3.3. Casting data inspection

After investigating the steelmaking, the analysis of the casting is the next step [9]. During casting, several heats are sequentially cast. Due to the peculiarity of the process, it is also necessary to consider the environment of the heat / slab in question, which further increases the complexity of the task. The program for analyzing the casting process greatly facilitates the identification of problematic strand sections. Visualization of the strand sections burdened with non-steady state, the tendency of a given slab to surface or internal defects can be more easily determine..

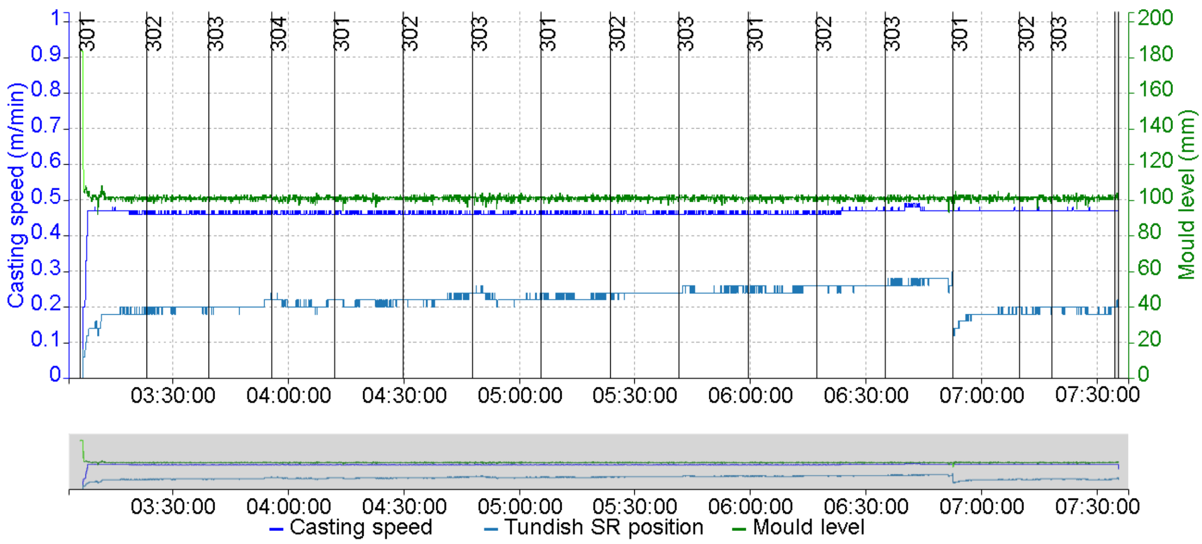

Figure 2. Casting curves

The curves in Figure 2 shows the events with the greatest impact on the strand:

- In the beginning of the casting, the temperature of the casting machine is not considered to be constant, and therefore the starter slab is often subject to surface defect formation based on operational experience.
- During the casting of the ending slab, the steel level in the tundish is lowered, causing contaminants / particles that are concentrated near the surface to enter into the mould due to the vortex effect.
- In the strand sections affected by deceleration, the stability of the crystallization process changes significantly, which, though to varying degrees, affects the strand in the entire casting machine (~ 10 m)
- Sudden high casting speed change or fluctuation of mould steel level can cause serious surface defects, especially at the liquid steel meniscus.

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- Changes in the position of the stopper rod of the steel flow regulator in the tundish can be inferreded from inclusion cluster adhesion, which affect the flow conditions, and inclusion cluster detachment, which cause the inclusion cluster to move into the mould.
- Formation of a transitional strand segment (so-called "mixed casting") resulting from the joining of heats with different compositional requirements (due to technological constraints) [10, 11].
- The strand sections affected by interventions are cut out if their nature requires it [12].

As mentioned above, the strand sections affected by major problems (e.g. casting speed change, level fluctuation, interventions) are cut / removed according to technology, thus causing no problem in the finished product sold, which has been confirmed by previous examinations. It is up to the skilled expert to judge other disorders affecting slabs.

Operating parameters often differ from the recommended manufacturing parameters. This difference is justified in most cases and is compensated by another technological parameter (which is also different, hence from the recommended value). In the fourth step, the system of compensation of these parameters should be examined.

- High steel temperature at the end of blowing or slower than expected cooling rate:
  - Longer argon stirring in the converter
  - Adding cooling scrap
  - Longer then prescribed bottom argon stirring in ladle
  - Upper argon stirring
- High level of active oxygen in the raw steel due to post-blowing
  - Longer argon stirring in the converter
  - Addition of deoxidizing agent in excess of prescribed
- Existence / absence of slag closure
  - The length of the tap time refers to the age of the tap stone. No new slag closure is required for new stone, as tapping stone formation and wear do not yet require
- High overheating
  - Reduction of/Reduced casting speed

3. Tendency factors

Based on experience, none of the steelmaking / casting differences / problems mentioned in the previous chapter cause problem in the rolled product by all means, they can only be considered as tendency factors. It can only be assumed that the combined effect of several factors may have caused the complained defect. The nature of the defect also depends to a large extent on whether the particular manufacturing conditions may have caused the defect.

Based on experience, the following circumstances generally justify the occurrence of some of the complained defects:

- High degree of overheating, above 40°C and starter slab
- Low quantity argon stirring combined with rapid cooling

4. Conclusions

It follows from the above that the investigation of the steelmaking and casting process of each complained product requires great expertise and attention. Most of the investigation aspects can be summarized in a constantly expanding knowledge base that can be programmed and thus automated. Expanded time diagram of the steelmaking process as well as the data displayed on the basis of the analysis of the casting curves are of great help to experts. Situations due to special circumstances (such as malfunctions due to human factors) and the continual expansion of the knowledge base will require the involvement of a specialist in the investigation process, but will greatly facilitate his / her work and thus allow deeper understanding and further analysis of the processes.

By exploring the relationships, it is possible to identify the conditions that influence quality in the technological process. Suspected defective strand sections can already be removed on the casting machine, or by using appropriate surface treatment (grinding, flame scarfing) to prevent surface defects on the rolled product. The measures taken on the basis of the above will reduce the amount of metallurgical defects in rolled products as well as internal problems which are not visible by surface inspection and which are detected only during processing at the customer. For these reasons, the system is beneficial from the points of view of both customer satisfaction and internal outcome.

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