BOF WEAR EVALUATION USING SOM (SELF ORGANIZING MAPS) AS A TOOL TO UNDERSTANDING, MODELLING AND IMPROVE PERFORMANCE & SUSTAINABILITY OF REFRACTORIES MATERIALS

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ABSTRACT

Refractories have been widely used in the lining of equipment in steelmaking plants, where a combination of chemical, mechanical and thermal phenomena cause the wear of these materials. Understanding the dynamics of this wear is important to guarantee a high-performance process. In such complex systems, computational techniques can be applied. Self-Organizing Maps is one of the techniques that can be used to select the main variables in the refractories wear system, which can then be used to model it and to optimize the lifespan of the refractories. In this way, production of new refractories can be reduced, which has high energy demand and high CO_2 emission from fuel burning in kilns and the process of calcination of carbonates. In this work, it's intended to model the refractories wear in LD convertors through Artificial Intelligence tools, aiming at understanding the process variables and improving performance and the lifespan.

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1 INTRODUCTION

Nowadays Linz Donawits (LD) converters in steelmaking plants are the main reactors used in steel production. The LD converters are commonly lined with MgO-C refractories, due to a series of excellent characteristics such as the high melting point and resistance to corrosion [1]. The wear of these refractories is often a result of mechanical, chemical and thermal phenomena combined in a multivariable complex system [2].

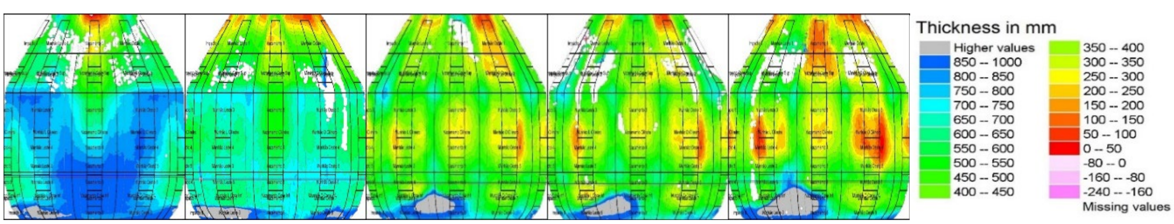
To make sure that the steel production is conducted safely and with reliable performance, it`s vital do understand the relation between the refractories wear and the observed operational variables. Nowadays, new approaches using Artificial Intelligence (AI) tools for data analysis are more and more frequent to evaluate and model different aspects of refractories wear. Several approaches have been used to improve the understanding of wear mechanisms and operational parameters and their variables with various levels of success for tasks such as prediction and control [3]. Self-Organizing Maps (SOM), a popular type of AI algorithm, present some unique traits in classification, segmentation, pattern recognition and feature selection [4]. It can simplify complex problems with high dimensionality into a simple bidimensional representation of the data.

Considering the advantages and opportunities that these novel computational tools offer, this work focused on the application of SOM to select the main variables that impact the wear rate in the LD converters trunnions, and thus reducing the dimensionality of the system, allowing for future prediction, control, and optimization. This study was carried alongside classical statistical techniques, for evaluation and comparison of these two techniques.

2 DEVELOPMENTS (MATERIAL AND METHODS)

The work is consisted of two parts: statistical analysis (mainly time series) and computational analysis (SOM) of the available data. The data is composed of 3 recorded campaigns with high, medium and low performance (named A > 4,000 heats, B ~ 4,000 heats and C < 4,000 heats) from the operation of a LD converter, focusing on its trunnions and its refractories wear rate. The refractories rate was calculated by the determination of its thickness over time (number of heats), and the measurements were done with the help of the FERROTRON™ system (laser scan), that generates data and figures of the perceived thickness trough timed measurements (figure 1). The statistical analysis was done by evaluating the plotted refractories wear against groups of operational data in order to analyze their effect on the rate. R programming language was used for the construction of the SOM algorithm. The parameters of the algorithm were selected according to [5].
For the feature selection, a global distance between the SOM maps is calculated and its value is used to represent the overlapping topology of features. Using the refractories wear rate as the reference, these distances were calculated and ranked. This ranking was then used for the variable selection. The algorithm was also bootstrapped in a cyclic manner, where the same data is run through the system as many times as necessary while carrying the results from the last run for good statistical accuracy and convergence, as it is suggested in [4].

Figure 1 – Evolution of the thickness (in mm) laser scans over the LD life via FERROTRON™ on 49 heats (A), 622 heats (B), 1708 heats (C), 1767 heats (D) and 1998 heats (E) in accordance with the legend (F)



(A) (B) (C) (D) (E) (F)

3 RESULTS

The time series analyses are presented hereafter, in figures 2 to 7 and table 1. Through comparative study between campaigns, it is possible to verify the influence of the plotted process variables on the average wear rate of the refractories in an evolutionary way throughout the campaigns. In this case, the most relevant variables for the three campaigns were considered together.

Figure 2 – Evolution of the trunnion wear rate as a function of the FeO of the slag

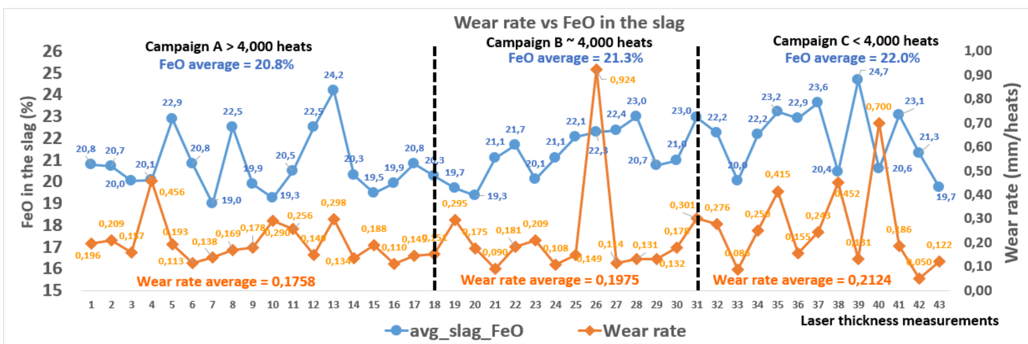


Figure 2 shows the FeO percentage increase in slag (avg_slag_FeO) between campaigns, with the campaign with the highest wear rate having the highest FeO content and the one with the lowest rate having the lowest content. This confirms that the variable is directly related to the slag oxidation levels that impact the carbon oxidation in the MgO-C refractory structure of the bricks, weakening the refractory and facilitating the entry of slag and, consequently, the dissolution reactions of MgO(s) in the refractory matrix by slag chemical components.

Figure 3 – Evolution of the trunnion wear rate as a function of the oxygen volume used in reblowing

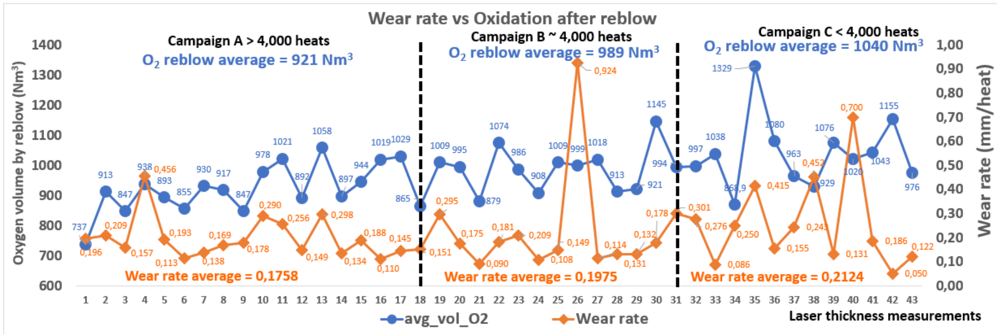
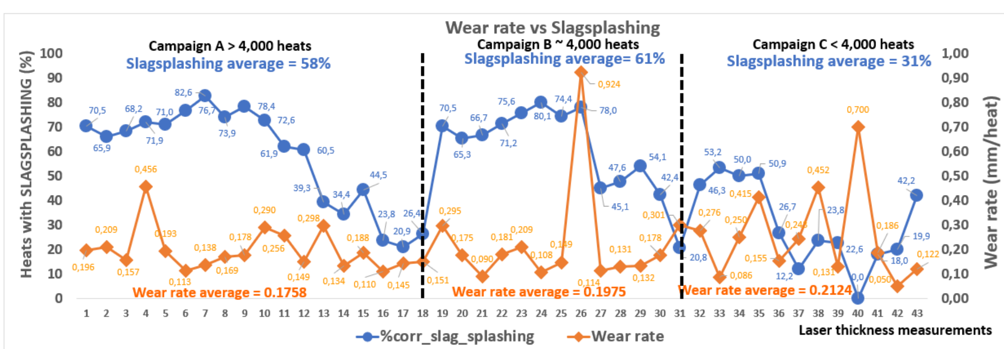


Figure 3 shows a clear influence of the volume of oxygen in the reblow (avg_vol_O2) in the increase of the wear rate. The reblowing of the heats causes a high level of oxidation of the slag and the metallic bath and increase the process times.

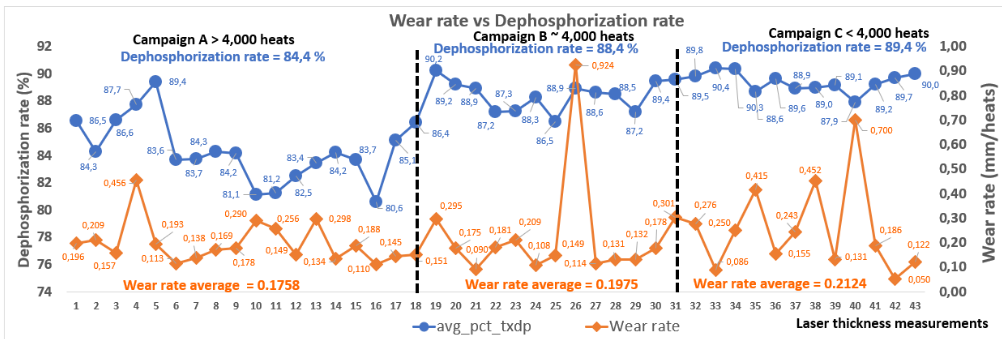
Through figure 4 it is possible to identify an inverse relationship between the percentage of heats in which the slagsplashing process was carried out (%corr_slag_splashing) and the refractory wear rate. This is due the coverage of refractories with slag, promoting a physical barrier that reduces the wear rate.

Figure 4 – Evolution of the trunnion wear rate as a function of the percentage of slagsplashing



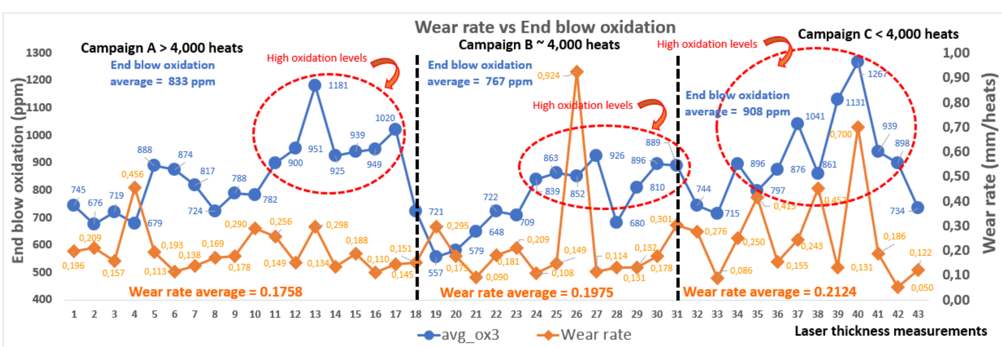
The direct correlation (effect) of the dephosphorization rate (avg_pct_txdp) in the LD campaigns is very evident in the sections indicated in figure 5, as the resulting oxidation levels for obtaining satisfactory phosphorus percentages in the final steel are extremely deleterious to the refractory structure, mainly due to the oxidation of the refractory carbon.

Figure 5 – Evolution of the trunnion wear rate as a function of the dephosphorization rate



As can be seen in figure 6, the level of oxidation of the metallic bath and slag (avg_ox3) at the end of blowing is directly related to the refractories wear rate, explained by the oxidation of carbon in the brick and the dissolution of MgO aggregates by a slag rich in FeO.

Figure 6 – Evolution of the trunnion wear rate as a function of the average level of oxidation of the metallic bath at the end of blowing



The process time (avg_Process_time), indicated in figure 7, proved to be representative of the wear rate, as longer contact times between the refractories and metallic bath and slag result in greater exposure to the thermal conditions of the process.

Figure 7 – Evolution of the trunnion wear rate as a function of the process time.

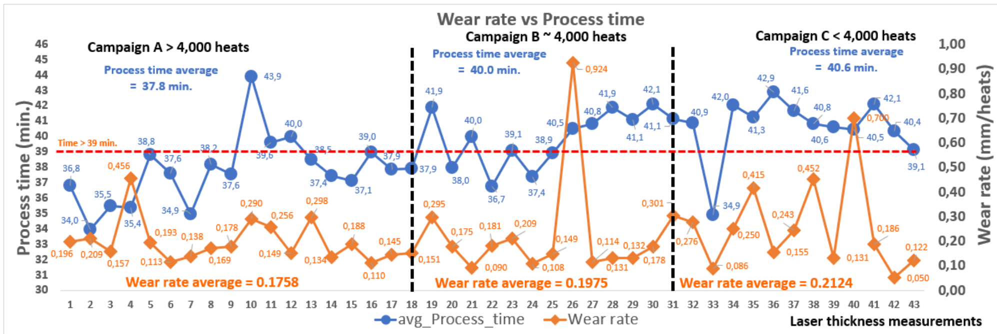


Table 1 – Summary of the influence of the main variables that impacted the wear rate of the trunnions' refractories in the three analyzed campaigns (A, B and C) of the LD

Variables	Campaign A	Campaign B	Campaign C
Refractory wear rate (mm/run)	0.1758	0.1975	0.2124
Average process time (minutes)	37.8	40.0	40.6
Average steel oxidation at the end of blowing (ppm)	833	767	908
Average slag FeO (%)	20,8	21,3	22,0
Average blowed O_2 in reblow	921	989	1040
Average rate of dephosphorization in the LD (%)	84.4	88.4	89.4
Heats with slagsplashing (%)	58	61	31

Summarizing table 1, the combination of high levels of oxidation of the metallic bath and of the slag, together with high process times and low surface protection of the trunnions' refractories seem to determine the general behavior of the wear rate. This is particularly evident in processes that involve high rates of dephosphorization of the metallic bath, either due to high levels of phosphorus in the pig iron and/or low levels of phosphorus in the final steel. The SOM analysis is presented in figure 8 to 10, and through topology analysis is possible to identify the relations between operational variables and refractories wear rate.

According to figure 8, that longer process times together with lower percentages of MgO in the slag affect the refractories wear rate direct, in alignment with the results from the statistical analysis. The low MgO slag content induces a chemical gradient between refractory MgO and slag, inducing a migration of this compound from refractory to slag. The same alignment is seen in figures 9 and 10, where the same relationships observed in the statistical analysis were observed via SOM maps.

Figure 8 – SOM analysis, wear rate vs process time and slag MgO percentage

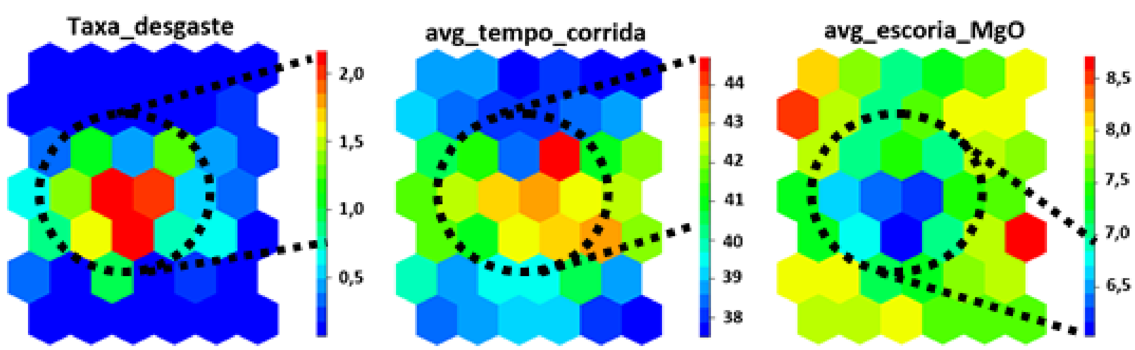


Figure 9 – SOM analysis, wear rate vs volume of oxygen blown in the reblow and the percentage of FeO in the slag

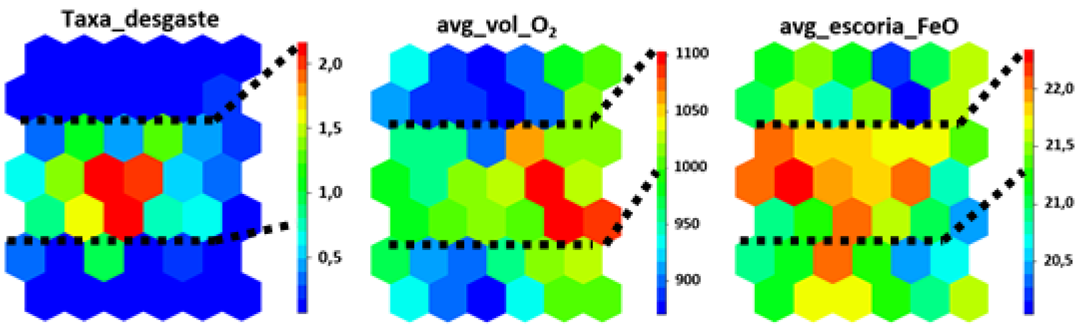
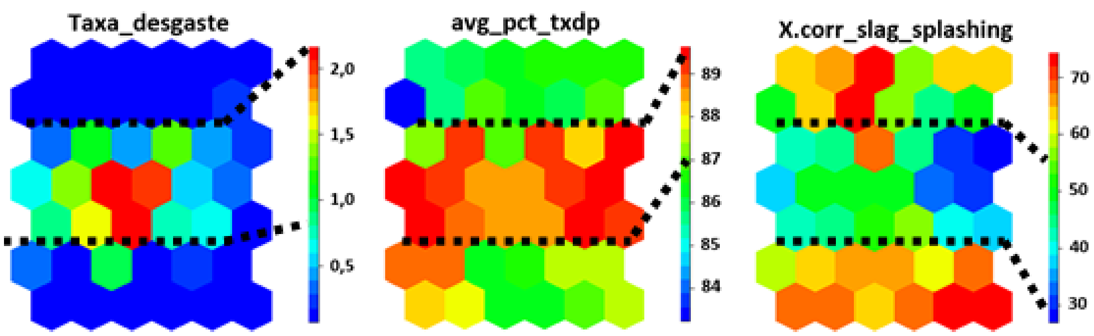


Figure 10 – SOM analysis, wear rate vs dephosphorization rate and the percentage of heats with slagsplashing



4 CONCLUSIONS

The similarity between methods indicates that the computational tool can be used in the analysis of the studied data as long as the quality of the input is observed, as triage and cleaning was necessary to remove inaccurate or inconsistent data.
After the selection of the dominant variable, it is possible to build a model of the wear rate considering the physical-chemical, thermodynamics, metallurgical variables, and engineering process parameters, which could better explain the process. Building the model is, however, not the end of the process, as data changes over time and operational adjustments are necessary to produce high-quality steel. The AI model is supposed to adapt continuously. Otherwise, the predictions of the model will be inaccurate.

In this study, the statistical analysis and the SOM tool proved to be equivalent and complementary. It’s concluded then that SOM and statistical models can make together great improvements on refractories wear modeling by decreasing, in an analytical way, the number of significant variables that control the refractory wear.

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