DATA SCIENCE FOR PRODUCTION OF MORE SUSTAINABLE CASTABLES WITH INCREASED AMOUNT OF SCRAP MATERIAL

Felipe de Campos Carreri*, Pedro Henrique Gomes, Bianca Maria Gomes da Silva, Nilton Fernando dos Santos Januário, Eric Yoshimitsu Sako, Douglas Fernando Galesi

Saint-Gobain Performance Ceramics and Refractories, Vinhedo, Brazil

*felipe.carreri@saint-gobain.com

ABSTRACT

Refractory castables nowadays contain low amounts of scrap material in their composition which prevent their life cycle from being more sustainable. Such scrap, for instance that originated from torpedo cars, may present large percentages of impurities and carbon, with considerable variations in each batch. This causes several difficulties in any attempt to incorporate it into castables without interfering with its properties such as flowability, porosity, packing, wear and corrosion resistance. In this work, a data science and analytics approach was used to evaluate the influence of raw and scrap materials on those properties in order to find improved compositions that allowed for an increase as high as 100% in the amount of incorporated scrap, without damage to the properties and performance of the original refractory. With such results, the consumption of 1,200 ton/year of virgin raw material could be avoided, corresponding to a reduction of 1,700 ton/year of emitted CO2.

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1. INTRODUCTION

Refractory materials enable the production of iron and steel worldwide. Used in several different stages of the iron and steelmaking, this industry consumes about two-thirds by weight of world refractory production. Experts estimate that the refractory material remaining after use is 30% of the material applied. This implies the generation of millions of tons of refractory waste which is a significant environmental and sustainability challenge[1].

Incorporating waste scrap in the production of plain refractories is a complex subject, but it is an important strategy to ensure a more sustainable product. To achieve this, the processing of the refractory waste is crucial, and it usually starts with the classification of the materials in different categories, followed by the removal of slag and metal and crushing the materials to different particle sizes[2]. The use of these materials requires proper management of particle sizes, which depends on the type of application. In the case of castables, as the proportion of incorporated recycled material increases, more water is required for the material to flow, usually resulting in a more porous concrete, less resistant to wear. Also, completely removing iron and slag residues from the spent refractories might not be possible and the presence of small amounts of SiO_2 or CaO will interfere as well in the wear resistance properties. Therefore, reports have shown a limit around 20% for the maximum content of recycled material[2].

Regarding the experience of Saint-Gobain´s refractories plant in Brazil, recycled torpedo ladle´s scrap have been locally available and used for the production of Al_2O_3-SiC-C based castables, although the maximum content of recycled material has been around 6%, above which the properties of the refractory are severely affected. Local torpedo ladle´s scrap has a similar composition to Al_2O_3-SiC-C materials, but with amounts of

SiO_2 that can be as high as 10% and carbon content also around 10%, imposing clear restraints on wear resistance and flowability to these castables.

The efforts to improve the materials or to increase the amount of incorporated scrap have been costly and laborious, usually based on a deep knowledge of materials science, refractory engineering, combined with empirical methods and trial-and-error procedures. In this context, a simple data science based approach can be very helpful to develop materials with less experimental effort.

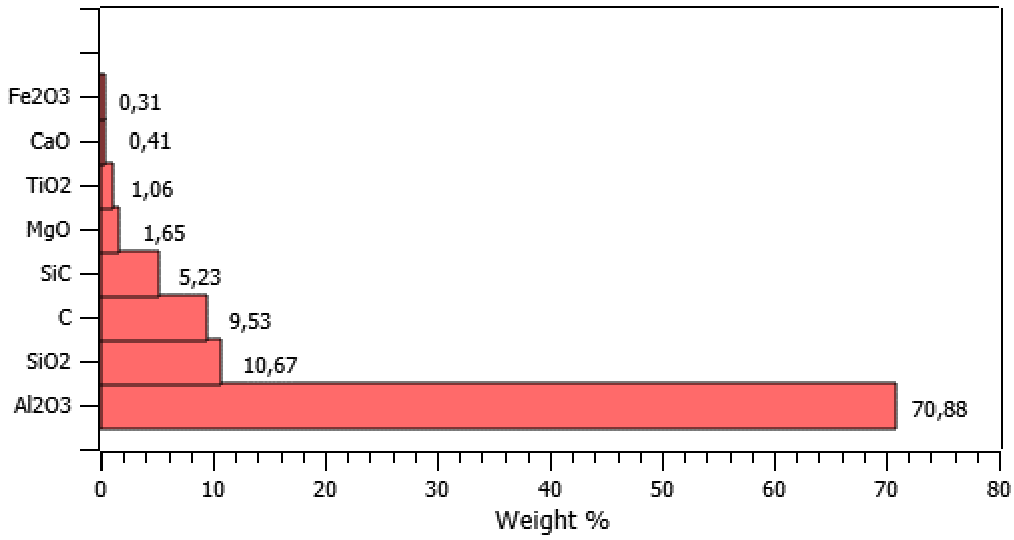
Data science has two primary components. The first is identified as Data Management and relates for instance, to storage, aggregation, archival, retrieval, and sharing of data. It deals with guarantying easy access to reliable data. The second component of data science is Data Analytics and deals with retrieving high-value information from the data by means of techniques like statistical analysis, pattern recognition, data visualization, machine learning and so on. The data analytics techniques are varied and always customized for different application domains[3].

In this work, the company´s production and quality department´s databases were used to access data about different materials and products and a simple data visualization scheme to acquire valuable information about the relation between castable material´s formulations and their properties. In this way, it was possible to identify raw materials that could compensate for the negative effects that scrap materials bring to the refractory´s properties. Experimental tests were carried out, directed by the insights obtained from the data analysis, and the expected results were obtained, allowing for an increase in scrap material content from 6% to 12%, which represents a 100% increase in potential usage of recycled materials.

2. CHEMICAL ANALYSIS OF SCRAP MATERIAL

Recycled torpedo ladle´s scrap obtained locally was analyzed by Fluorescence Spectroscopy and by Carbon Combustion Analysis (LECO). This is the material which was incorporated to freshly produced castables as scrap. The chemical composition of the material was determined as follows:

Figure 1 – Chemical composition of torpedo ladle´s scrap.

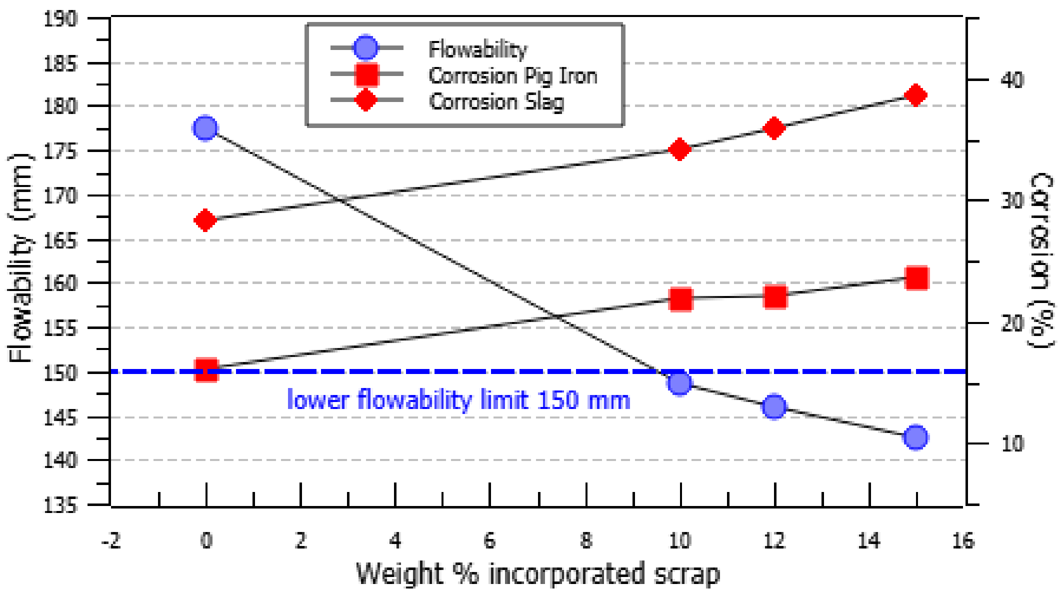


As shown by the chemical analysis, the material contains considerable amounts of SiO_2, around 10%, which is thought to have a negative impact on the wear resistance of castables to which it is added. Also, the carbon content around 10% as well should have an impact on the flowability of the concrete containing the scrap. The material also contains minor amounts of other contaminants such as MgO, TiO_2, CaO and Fe_2O_3 which in low concentrations, are not expected to affect the properties of the concrete significantly.

3. PRELIMINARY TESTS WITH INCREASED AMOUNT OF SCRAP

Torpedo ladle´s scrap was incorporated into Saint-Gobain´s standard castable in weight percentage amounts of 10 %, 12 % and 15 %. Flowability was measured by filling a metallic mold with concrete and pouring it in the center of a vibrating table, which is vibrated 15 times for 1 second. The diameter of the spread castable is measured in two points and the average is calculated. Original flowability, without scrap incorporation is around 177 mm. As can be seen in figure 2, for constant water content, the flowability decreases as the amount of incorporated scrap increases. This is related to the grain size of particles in the scrap and also the high amount of carbon in the scrap material. For amounts of 10% and beyond, the flowability is below the acceptable lower limit for most applications.

Figure 2 – Flowability and corrosion behavior of castable concrete with increasing amount of scrap material. 0% incorporated scrap corresponds to original material.



Pig iron and slag corrosion tests were performed in a rotary furnace at the temperature of 1450°C for 2 hours. Corrosion in percentages are determined by comparing the dimensions of the test samples before and after the corrosion test. The corrosion behavior of the concrete also gets worse with increased amount of scrap, mainly due to the presence of SiO_2 in the scrap. After these preliminary tests, a simple data science based technique was used to identify raw materials that could compensate for the negative effects of the scrap in refractory castables.

4. DATA MANAGEMENT

For materials science, data can be collected from different sources. These may include files produced by laboratory equipment and instruments, notes and reports containing pertinent details about experiments, environmental conditions, method of preparation of test specimens, instrument settings, and so on[3]. For this work, data was collected from the production plant´s database for four different castable products and from the previous three years of registered data, from 2019 to 2021. This included the production order number, the product´s name, raw materials present in the formulation, the weight percentage of each raw material in the formulation and the amount of water in the mixture. Also, data was collected from the quality laboratory´s database for samples from each of the production orders. The monitored properties were flowability, density, porosity, compression and flexural modulus. The four different evaluated castable products comprised of similar materials, all based on the Al_2O_3-SiC-C system, but with varying formulations according to different applications.

First, it was necessary to join data originated from different databases into a single dataframe, with a layout that could be standard, uniform and suitable for further manipulation. Then, a “data cleaning” procedure was performed, in which incomplete, faulty or abnormal data needed to be identified and removed from the database. After these steps, the data was suitable for further analysis.

5. DATA ANALYSIS

For this work, an interactive data visualization scheme was programmed in Python utilizing the Bokeh Visualization Library[4]. Formulations from different production orders were represented in a stacked bar chart and arranged in order according to increasing flowability properties. The interactive chart allowed to select the desired raw material to be visualized in the chart. In this way, it was possible to visually identify raw materials that could influence the flowability (increasing flowability levels with increasing weight % of the raw material in the formulation). A few examples are shown in the following figures.

Figure 3 – Weight % of alumina source #1 plotted against flowability for different production orders, arranged in order with increasing flowability. Formulations with higher weight % of the raw material usually present higher flowability.

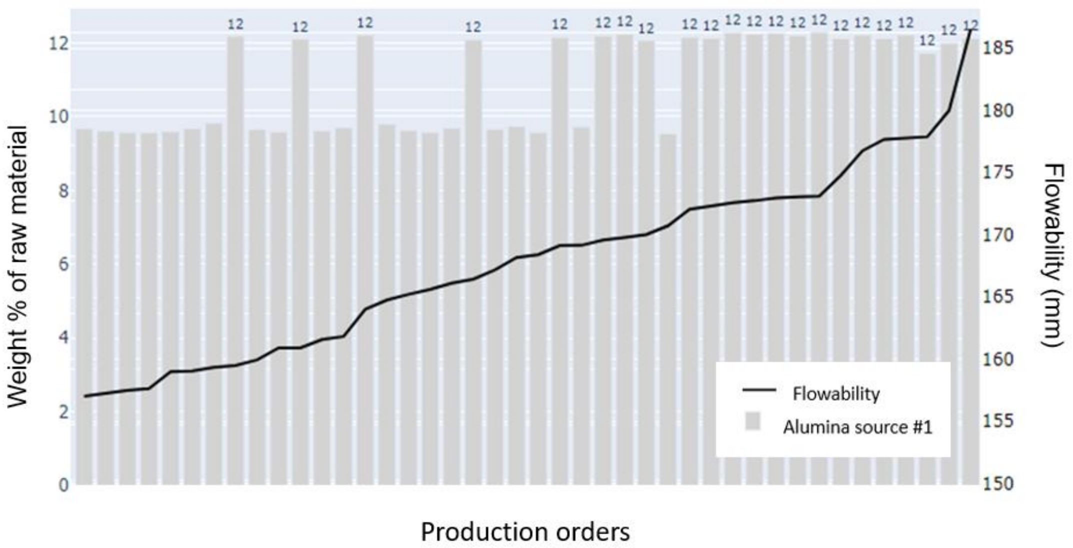
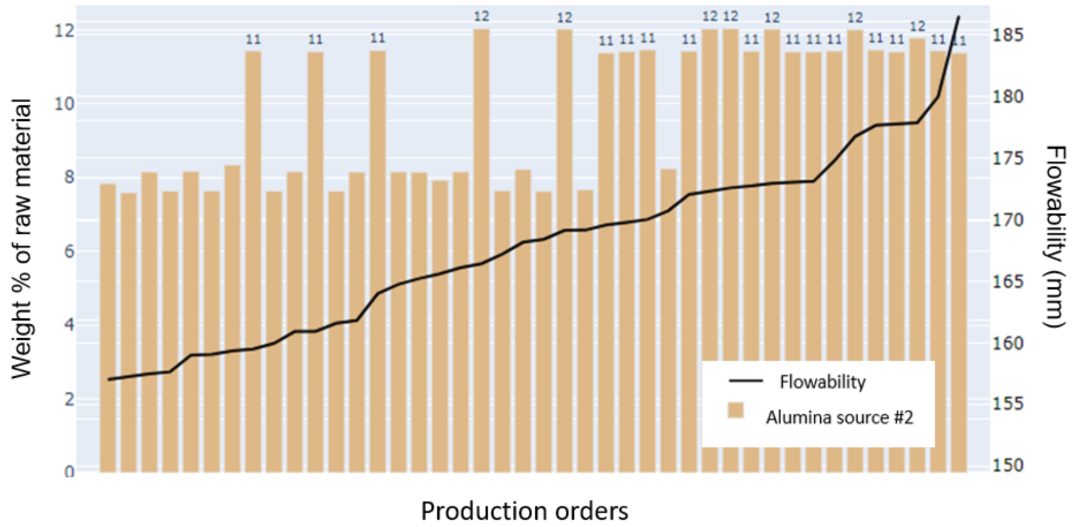


Figure 4 – Weight % of alumina source #2 plotted against flowability for different production orders, arranged in order with increasing flowability. Formulations with higher weight % of the raw material usually present higher flowability.

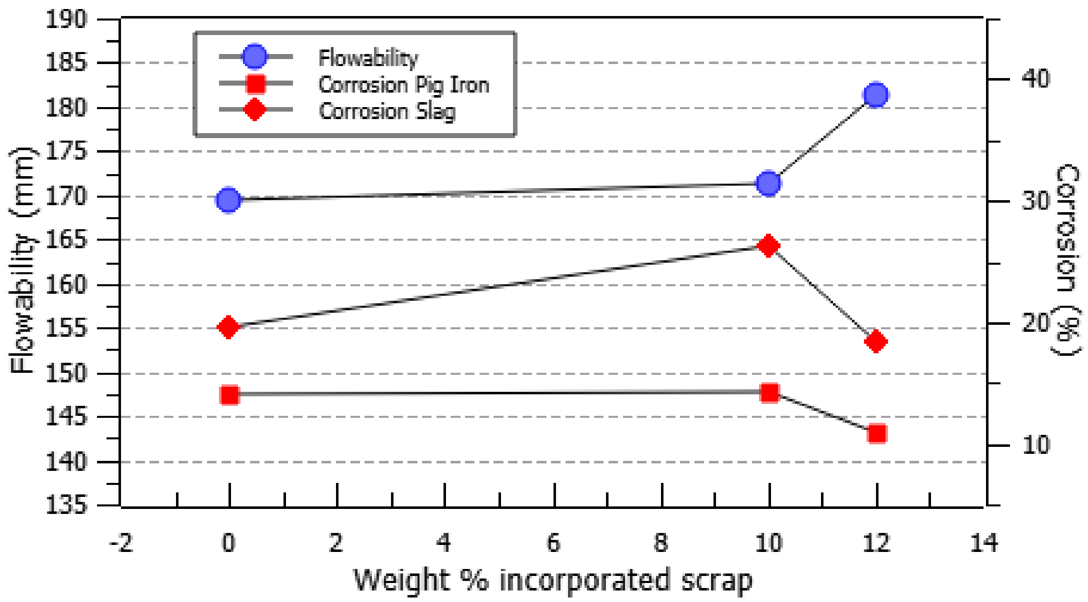


For the sake of intellectual property, it will not be possible to disclose which raw materials present the closest relationship with the castable flowability, but it was clear that some of them, such as the alumina sources presented in the figures above, are significantly beneficial for increasing flowability whereas others showed inversed correlation, helping to decrease the flow values. From these results, different formulations with increased amount of scrap material were tested, with adjusted amounts of other raw materials to compensate for the effects of the scrap.

6. TESTS WITH INCREASED AMOUNT OF SCRAP AND COMPLIMENTARY RAW MATERIALS

Torpedo ladle´s scrap was once again incorporated into Saint-Gobain´s castable in weight percentage amounts of 10 % and 12 %. This time, complimentary raw materials identified from the previous data analysis were also added or had their weight % adjusted. Comparing the results in figure 6 and figure 2, it is possible to see that the new formulation´s flowability was maintained in acceptable ranges, even with scrap weight percentage of 12 %. The corrosion behavior was also maintained at acceptable levels, similar to that of the original material.

Figure 6 - Flowability and corrosion behavior of castable concrete with increasing amount of scrap material and presence of complimentary raw materials. 0% incorporated scrap corresponds to original material.



7. CONCLUSIONS

Just increasing the amount of scrap material into our castables leads to degraded properties in terms of flowability and corrosion resistance of the concrete. Nevertheless, by using simple data science and data visualization techniques, it was possible to identify complimentary raw materials that when added to the formulation, kept the material properties in acceptable ranges close to the original material, even with higher amounts of incorporated scrap material, up to 12 % in weight, which represent a 100 % increase in scrap incorporation compared to what is currently practiced in our product. With such results, the consumption of 1,200 ton/year of virgin raw material could be avoided, corresponding to a reduction of 1,700 ton/year of emitted CO2.

8. REFERENCES

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