Novel Castable Technology for a Safe and Extended Lifetime of Blast Furnace Main Troughs

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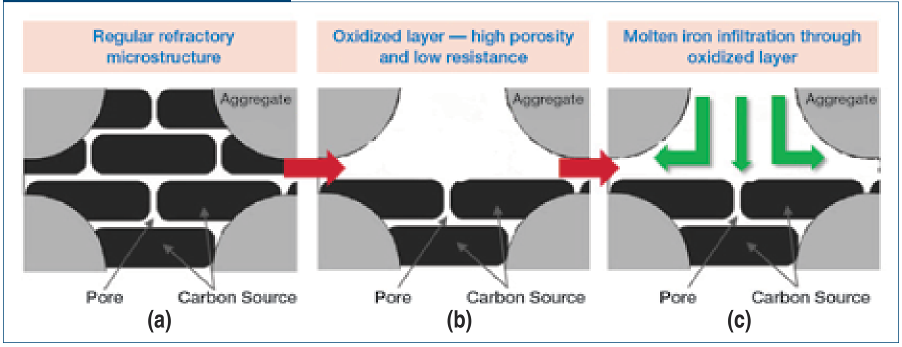
Due to the constant thermal cycling and the direct exposure of the refractory lining to oxidizing environments during the main trough operation, the standard Al_2O_3-SiC-SiO_2-C castable can be easily damaged and the trough campaign consequently reduced. When events like this happen, emergency repairs must be executed, resulting in increased refractory unit consumption and an unplanned shutdown of unit operation. This paper discusses a castable technology that provides opportunities to guarantee a reliable campaign without any risks and also reduces the number of hours spent in trough repairs.

Steel production in some integrated mills comprises blast furnace operations limited by two tapholes and, therefore, requires strict attention during repair procedures in the casting house. When there is refractory maintenance in one of the main troughs, blast furnace production is carried out in a system of consecutive castings using only one taphole. In this case, the furnace drain-out is not balanced and the pig iron constant flow leads to a concentrated wear in the hearth, very close to the side of the operating taphole. For this reason, the troughs must be available for operation as quickly as possible, and therefore the time spent for repairs is always limited.

As there is very little time for cooling, the demolition step takes place during hot conditions, exposing the residual refractory lining to intense oxidation. When SiC and carbon are oxidized, the castable structure is compromised due to the higher porosity, and its corrosion resistance is significantly reduced,[1,2] as illustrated by Fig. 1. Moreover, due to some issues in the back lining profile, oxidation is also intense in the cold face of the working lining, which makes this mechanism the most aggressive for the Al_2O_3-SiC-C castables in the main troughs.

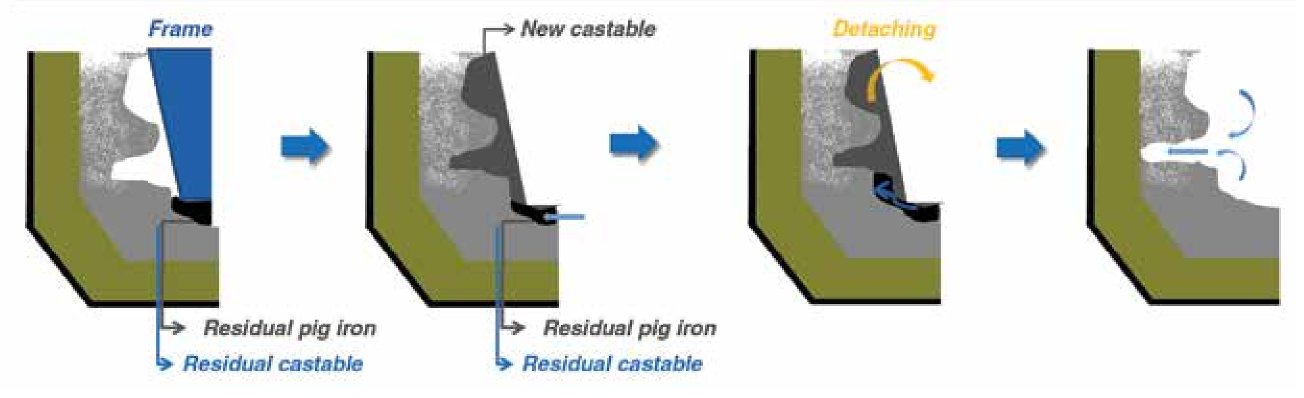
In order to avoid an undesired increase in the wear rate during the trough campaign by the contact between molten pig iron and the oxidized castable, the working lining is mostly replaced during the trough repairs. Nevertheless, the high temperature faced in those occasions also leads to a poor adhesion between the new material and

Figure 1



Oxidation mechanism of Al_2O_3-SiC-C castables: regular structure (a); oxidized structure (b); and infiltration of molten iron (c).

Figure 2



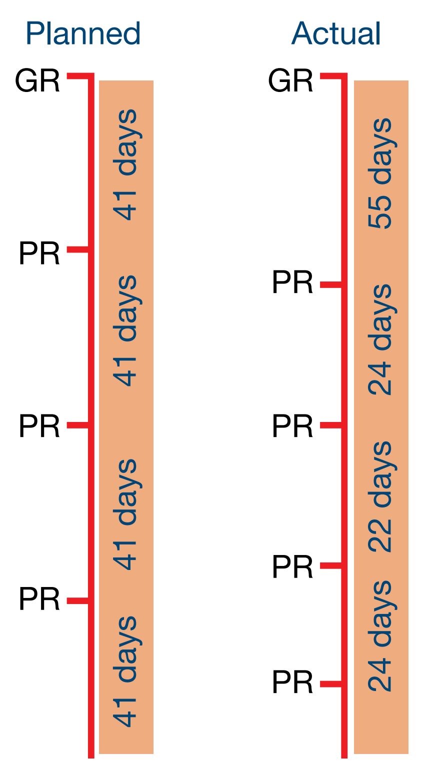
Wear mechanism during trough operation: new castable is detached during operation and the wear rate increases as the molten iron reaches the oxidized layer.

the residual one and, as a consequence, the just-installed castable could easily detach from the base material during the early stage of operation.[3] As described in Fig. 2, when that happens, the oxidized residual material is exposed to molten iron and corrosive slag attack, increasing the wear rate and demanding an unplanned stoppage for refractory repair. That chaotic scenario interferes with the blast furnace operation, as the trough availability becomes much different from that which was planned. Fig. 3 shows the comparison between a planned trough campaign and the actual one.

The direct solution for that main hurdle to the furnace operation could be the development of a new technology of Al_2O_3-SiC-C castables focused on extremely high oxidation-resistant materials. The oxidation mechanism takes place when oxidizing sources, such as O_2, CO or H_2O, for instance, interact with C, SiC or other non-oxide compounds, mainly at high temperatures. The most effective way to prevent oxidation is, therefore, to create barriers in order to avoid the direct contact of the refractory with those gases. That is usually attained by using additives, which generate a glassy phase at high temperatures and create a chemical protection inside the refractory structure. The main drawback related to this practice is the reduced corrosion resistance due to the presence of such low-melting-point phases. Aware that this practice would not work well, Saint-Gobain devised a different alternative: decreasing the refractory contact with gases by controlling the grain size distribution and by forming dense structure with another deflocculant, consequently reducing the castable porosity.

The present work addresses the results of such novel and innovative technology, which not only showed very interesting lab results, but also led to a significant trough life improvement, helping to keep a stable and safe blast furnace operation.

Figure 3



Comparison between planned trough campaign and actual one. GR: General repair; PR: Partial repair.

Experimental Procedures

Without any change in the overall chemical composition, as observed in Table 1, the novel technology designed to improve the castable oxidation resistance was based on three main modifications on the original composition: an optimization on the grain size distribution, the use of a special deffloculant and the combination of oxidant inhibitors. The new developed castable (hereafter denoted as "S25-NG" – NG stands for "new generation"), designed according to such innovative concepts, was comparatively evaluated with the previous castable used at blast furnaces main troughs (hereafter denoted as "S25-S – S stands for "standard").

For samples preparation, the castables were mixed for 5 minutes following a two-step water-addition procedure used by Pileggi et al.[4,5] After mixing, the samples were cured at room temperature (~25°C) for 24 hours and dried for an additional 24 hours at 110°C.

The following physical properties were evaluated after drying at 110°C and after firing at 1,000°C/5 hours and 1,450°C/5 hours in a reducing atmosphere:

- Cold crushing strength (CCS): measured according to ASTM C133-94 standard, using cubic samples of 40 mm x 40 mm x 40 mm.
- Modulus of rupture: carried out under three-point bending tests (ASTMC 583) using prismatic samples (160 mm x 40 mm x 40 mm).
- Open porosity and apparent density: evaluated by using the Archimedes technique in kerosene, following the ASTM C380 standard.

Corrosion tests were conducted in a high-frequency furnace, using samples calcined at 400°C for 5 hours. As the corrosive agent, a mix of blast furnace slag and pig iron was used (80% slag + 20% pig iron for slag attack test). Table 2 presents the chemical composition of the blast furnace slag used in the tests. The testing took place for 4 hours around 1,550°C and the slag + pig iron mix was changed each hour.

At last, oxidation resistance tests were carried out according to the following procedure: cubic samples of 50 mm x 50 mm x 50 mm were prepared and prefired for 5 hours at 1,000°C, in reducing atmosphere. The samples were then placed inside a pre-fired furnace at 1,000°C, under oxidizing atmosphere, so they could go through an aggressive oxidation process. They were withdrawn after 6 hours or 11 hours and, after cooling down, they were cut and the cross-sections were used for measuring the oxidized layer.

S25-NG castable was also installed at a blast furnace main trough in order to run a pilot trial and confirm the results attained at lab scale. After 250 days of operation, a post-mortem sample was brought back to laboratory and chemical analysis through x-ray fluorescence was performed at different regions in order to analyze the carbon and SiC content in the castable structure after use. The results were compared to the ones attained with S25-S post-mortem sample after operating a similar campaign (roughly 250 days too).

Table 1

Main Differences Between S25-S and S25-NG

	S25-S	S25-NG
Al_2O_3 (wt.%)	68	68
SiC + C (wt.%)	28	28
SiO_2 (wt.%)	1.5	1.5
Additives	Regular deflocculant	Special deflocculant + oxidant inhibitor
Water (wt.%)	5.2	4.4
Flow values (mm)	160	158

Table 2

Chemical Composition of the Blast Furnace Slag Used in the Corrosion Tests

SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	MnO	Basicity B2
34.0	45.5	10.4	0.4	5.5	0.7	1.3

Results and Discussion

Table 3 presents the physical properties of S25-S and S25-NG after drying at 110°C/24 hours and thermal treatment at 1,000°C/5 hours and 1,450°C/5 hours.

With a more packed structure and an improved dispersion of the matrix components, the newly developed castable demanded much less water during its process when compared to the standard material, as shown in Table 1, contributing to reduce its open porosity value (Table 3). The lower values of mechanical strength for S25-NG after firing at 1,000°C and 1,400°C are associated with the amount of carbon in the composition, which affects the sintering process and inhibits the excessive sintering at high temperature.

As predicted, such reduced porosity of the novel developed castable was essential to ensure an excellent oxidation resistance, even after long exposure to air. Fig. 4 shows the castable cross-sections after the oxidizing test, whereas Table 4 presents the oxidation index of both materials calculated by the cross-section areas measurements.

One can easily notice that, owing to the innovative concepts used for the formulation design, S25-NG presented an outstanding performance when exposed

Table 3

Physical Properties of S25-S and S25-NG After Heat Treatment at Different Temperatures

		S25-S	S25-NG
Apparent density (g/cm^3)	110°C	2.95	2.96
	1,000°C	2.93	2.92
	1,450°C	2.92	2.93
Open porosity (%)	110°C	14.3	12.2
	1,000°C	20.3	17.9
	1,450°C	18.6	17.6
CCS (MPa)	110°C	21.3	20.5
	1,000°C	41.6	38.4
	1,450°C	72.3	28.5
MoR (MPa)	110°C	7.6	7.0
	1,000°C	9.0	7.6
	1,450°C	14.3	6.0

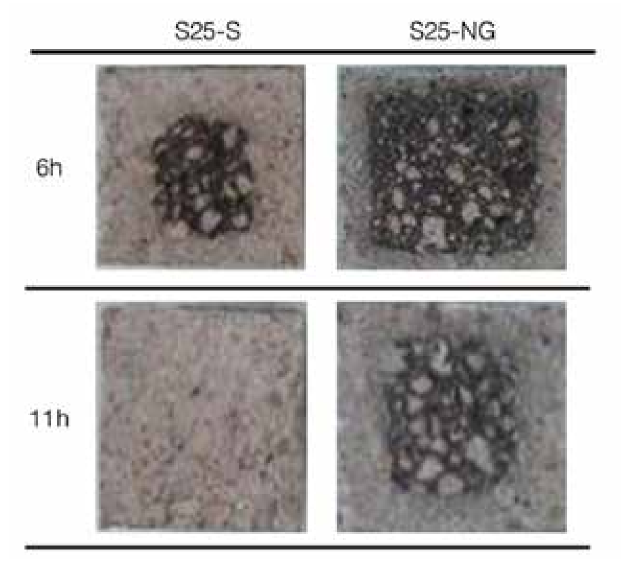
to air at 1,000°C, which is the most critical temperature for Al_2O_3-SiC-C castables, even after 11 hours. Differently from S25-S, which presented no longer any residual carbon content, S25-NG kept most of its original structure. As a low oxidation rate leads to small variances on the castable porosity, those results indicate that the material's corrosion resistance would clearly be increased during use.

In order to evaluate the effect of the different oxidation rate on the corrosion resistance, a pig iron attack test was performed with both castables (Fig. 5). As expected, due to the combination of better particles packing, reduced porosity and, consequently, low oxidation rate, the new castable S25-NG presented an improved performance with a corrosion index 14% lower than the original one.

With promising results at lab scale, larger batches of S25-NG were produced and installed at a two-hole blast furnace for field trials. After 250 days of operation (with roughly 300,000 tons of pig iron throughput), a post-mortem sample was taken from the residual working lining, in a region close to the back lining (to ensure that the sample was representative to a portion of the base material that was not changed during any partial repair). The sample was then compared to another one from the standard material at the same conditions in terms of working life and location in the trough.

Fig. 6 shows pictures of the post-mortem samples of both materials, highlighting the regions where chemical analyses were performed. The results are expressed in Table 5. It is clear that the reason for trough campaign instability at blast furnaces with two holes was directly related to the poor oxidation resistance of S25-S. The SiC + C content of the

Figure 4



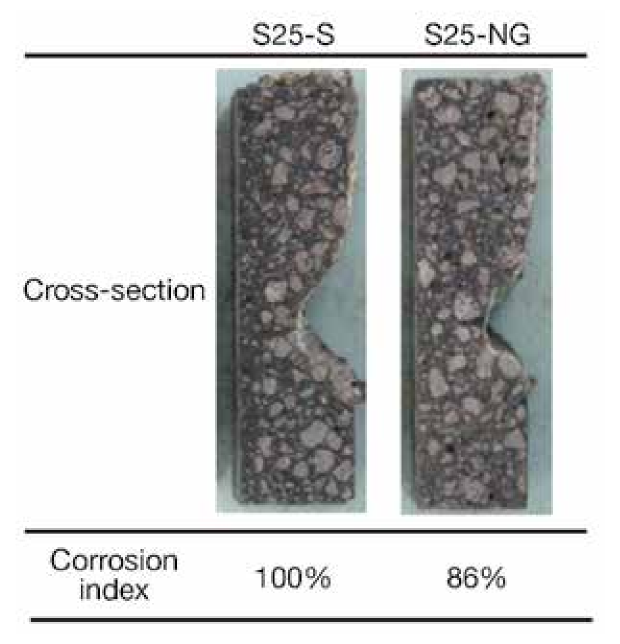
Cross-sections of S25-S and S25-NG samples after oxidizing test at 1,000°C for 6 hours and 11 hours.

Table 4

Oxidation Index of S25-S and S25-NG After Oxidizing Test at 1,000°C for 6 Hours and 11 Hours

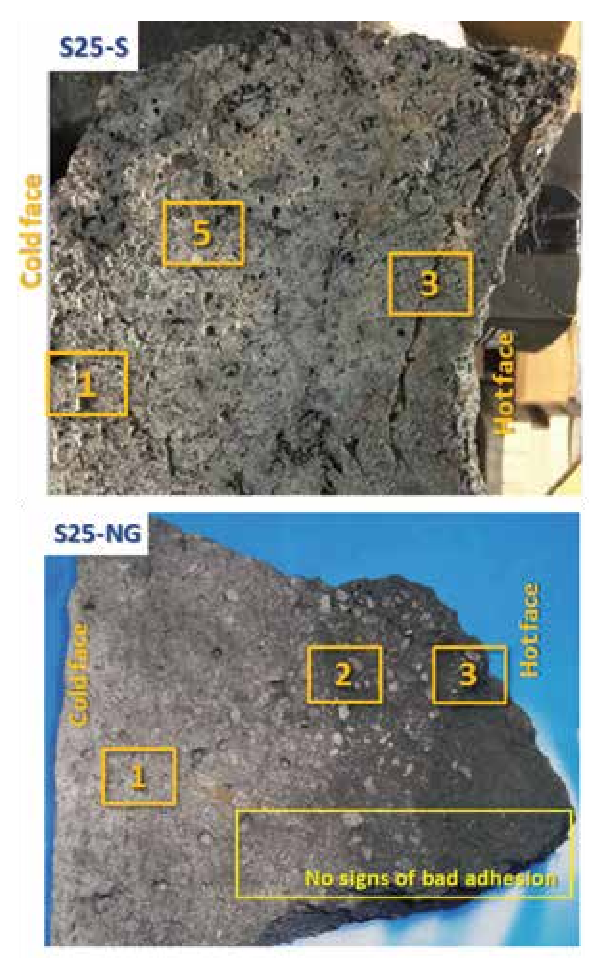
		S25-S	S25-NG
Oxidized layer (relative index)	6 hours	100%	46%
	11 hours	100%	39%

Figure 5



Corrosion index of S25-S and S25-NG after pig iron attack test at 1,550°C for 2 hours.

Figure 6



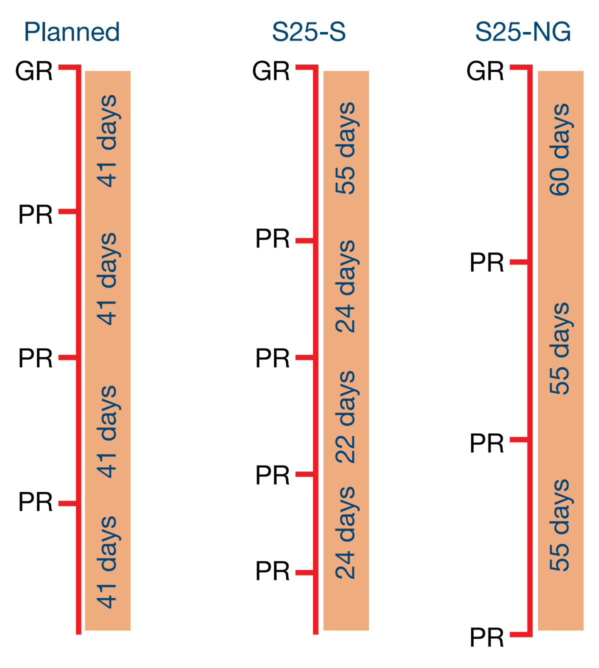
Post-mortem samples of S25-S and S25-NG after 250 days of operation.

Table 5

Chemical Analyses of Different Regions in the Post-Mortem Samples of S25-and S25-NG (results expressed in wt.%)

Material	Region	Al_2O_3	SiC + C	SiO_2
S25-S	1	62.2	11.7	22.4
	2	65.4	11.9	17.6
	3	59.6	13.7	16.2
S25-NG	1	68.3	19.4	9.6
	2	68.3	22.0	7.0
	3	64.7	27.0	4.9

Figure 7



Comparison between planned trough campaign and actual ones with S25-S or S25-NG.

post-mortem sample was significantly reduced when compared to the reference values presented in Table 1, mainly in the regions 1 and 2 (close to the cold face) where oxidation is constant during trough operation. The high oxidation rate is also evidenced by the high SiO_2 content in S25-S post-mortem sample, which resulted from SiC oxidation according to the following reaction:[6]

$$SiC + O_2 \rightarrow SiO_2 + C$$

Conversely, the S25-NG sample presented a much nicer structure after use, with very slight signs of oxidation. One can notice that in region 3, at the hot face, the SiC + C content barely changed, pointing out that the novel technology had positive outcomes at field trials as well. Additionally, the S25-S sample presented some visible cracks at the hot face, which are most likely related to its inefficient adhesion to the base material during the repair step. In the S25-NG sample picture, no signs of bad adhesion could be observed, which also helped to improve the material working life.

Due to those positives results, the S25-S castable was progressively replaced by S25-NG at a specific blast furnace in Brazil and long trough campaigns could be attained. In Fig. 7, a comparative evolution of the trough campaign is presented, where it is possible to observe that not only was the instability problem overcome, but also the intervals from repair to repair were extended. This result was of utmost importance to the production plan, as it resulted in a higher trough availability rate and consequently reduced the risks to the blast furnace operation.

Conclusions

A high-performance Al_2O_3-SiC-C composition based on an entirely novel anti-oxidation technology was developed in order to solve the trough instability issue at blast furnaces with two tapholes. Due to the combined use of a special defflocculant and the optimization of the particle distribution, the water required for mixing was reduced and the material's porosity was decreased. In addition, the novel castable could achieve an outstanding oxidation resistance by adding the oxidant inhibitor to the dense structure, which led to an extended campaign life during field trials. With S25-NG entirely implemented, a Brazilian blast furnace was able to operate with reduced risks and a very stable production plan, which directly impacted the productivity level and the furnace lining preservation.

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