High-Performance Taphole Clay: A Key for Blast Furnace Hearth Protection and a Tool for Cost Reduction

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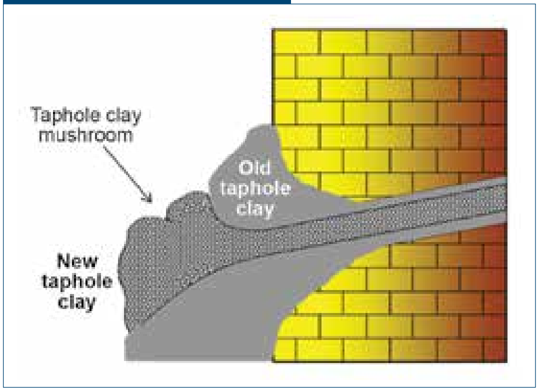
Oftentimes, blast furnace hearth wear becomes a bottleneck in lengthening the blast furnace campaign. The hearth's taphole area, which is severely eroded by the molten iron and intense slag flow, can become a challenge for stable blast furnace operation. This paper presents recent development on taphole clay technology, which has shown excellent results in increasing taphole length, creating a good protection for the hearth. Additionally, it is shown how a high-performance taphole can also reduce costs in the blast furnace operation.

In order to achieve profitable results in markets of commodity items, such as the competitive steel industry, producers must keep a constant focus on cost reduction and highly efficient production plans. Increasing the working life of some key equipment, for instance, is of utmost importance in steel plants, as it postpones huge stoppages for refractory repair. In the ironmaking sector, special attention is dedicated to blast furnace campaigns, which are mainly limited by the wear degree of the ceramic hearth. This specific region is severely eroded by the intense flow of pig iron and slag inside the blast furnace, and its deterioration may be accelerated in case of high production rate, high molten metal temperature and changes in the fuel composition (when higher injection of pulverized coal prevails over the regular rate of coke addition).[1,2] Other operational parameters also play a relevant role on the hearth walls wear, such as the Zn deposition and the changes on deadman position.

A suitable protection of the ceramic hearth is mostly dependent on the performance of the taphole clay.[3] When pushed into the furnace after each casting in order to completely seal the taphole, the clay accumulates close to the inner walls, generating a stable ceramic protection called "mushroom," as shown in Fig. 1.

Figure 1



Graphical representation of the "mushroom" formation inside the blast furnace during taphole clay pushing.

The use of a low-quality taphole clay leads to either an inefficient protection of the furnace walls or an increased amount of pushed clay required for rebuilding the eroded mushroom every each casting. Neither outcome is financially desired, as not only do the steel producers end up spending more money with taphole clay, but they will also have to shut down the blast furnace earlier than expected. Moreover, besides the hearth protection, the clay performance has a direct impact on the operation stability by assuring a controlled drainage of liquids from the furnace. Therefore, the taphole clay formulation must be designed based on an integrated solution sustained on three main pillars:

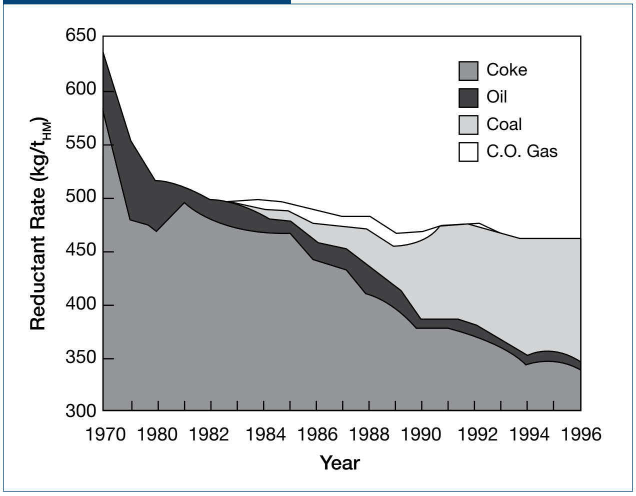
- High corrosion and erosion resistance, in order to withstand the aggressive attack by the slag and molten iron flow, resulting in long cast duration and uniform casting rate.
- Ability to stick firmly to the walls and to the old taphole clay present inside the furnace, helping to build a long and stable taphole length.
- Adequate plastic behavior and appropriate mechanical strength through the entire temperature range in order to avoid any issues during pushing and drilling.

It is also important to mention that blast furnaces operate differently from each other, according to the raw materials used (iron ore and pellets rate, coke reactivity, etc.), to the fuel composition (coke and pulverized coal balance), to its daily production, to its inner volume, to the equipment used during pushing and drilling, and to many other factors associated with the pig iron production process. Thus, although having to assure the three main features listed above, the taphole clay formulation must also be tailor-made for each furnace and its specific operational parameters.

Ferrosilicon nitride, silicon carbide, alumina and carbon sources are the main compounds present in taphole clay formulations. The adjustments performed to better design the taphole mix for a specific blast furnace are usually based on balancing the proportion of those main raw materials. Nonetheless, due to the current tied economic situation, the blast furnace environment has become much more aggressive to the taphole clay. The slag volume, for instance, has progressively increased as a consequence of the use of poorer raw materials, whereas the significant trend on coke rate reduction (as illustrated in Fig. 2)[4] has pushed the pig iron flow directly into a more abrasive contact with hearth walls. In this scenario, simple adjustments on existing formulations are not enough, and innovative technologies are fundamentally required for the development of high-performance taphole clays.

The present work addresses the development of a novel generation of taphole clay, which is able to attain long and stable taphole lengths, guaranteeing a reliable protection of the blast furnace hearth walls.

Figure 2



Rate of reducing fuels used in blast furnace operations through the years.[1] A clear trend on coke rate reduction can be oberved.

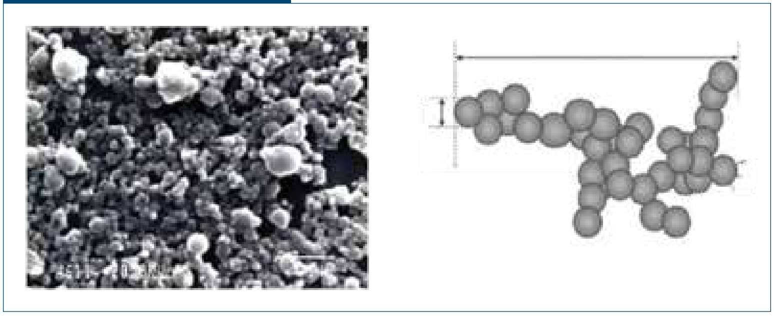
New Technology Concepts

Corrosion and Erosion Resistance — Al_2O_3-based raw materials are commonly used in taphole compositions in order to provide good chemical stability when in contact with the molten pig iron. On the other hand, silicon carbide presents an extremely low reactivity with the blast furnace slag. The proper balance between those two components is, therefore, of utmost importance when designing a high-corrosion-resistant formulation for a specific furnace. However, as stated above, the current operative conditions have combined a strong slag attack, due to the high slag volume, and a very abrasive pig iron flow, which limits the improvements based only on the adjustments of the Al_2O_3/SiC ratio. In the new taphole clay generation, a different approach was applied in order to overcome that hurdle: the grain size distribution optimization.

As already pointed out by many authors,[5,6] the corrosion mechanism of a ceramic body by a molten component is ruled not only by the chemical reaction itself, but also by the total contact surface available for that chemical reaction to take place. In other words, if the ceramic material presents high open porosity, the molten metal (or molten slag) would penetrate easily, generating a higher contact surface for reaction. As a consequence, the corrosion process advances quickly. Thus, when optimizing the grain size distribution, the taphole clay porosity is reduced, limiting the available surface for the reaction with slag and pig iron.

Additionally, it is also important to bear in mind that the material's mechanical strength is also entirely related to its porosity, as pores act as stress concentration mechanisms, helping crack propagation. Once the pore distribution is controlled, the clay mechanical strength could also be improved, leading to an efficient resistance against the intense pig iron flow.

Figure 3

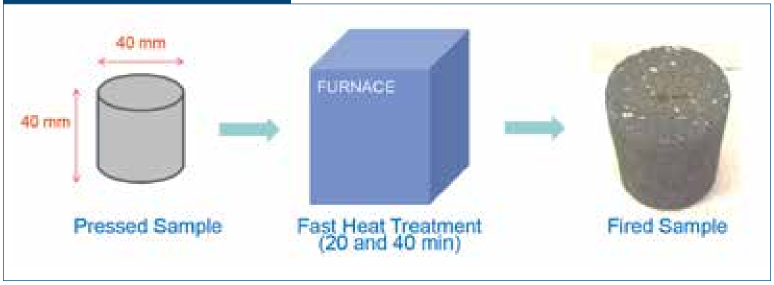


Structural configuration of additive “XY.”

Adhesion and Plastic Behavior — A taphole clay with high corrosion and abrasion resistance generates a very stable and tough mushroom, helping to keep long taphole length values. Nonetheless, in order to build such long values, the clay should also be able to firstly fill in properly all the taphole, without any molten metal infiltration or sealing problems. Moreover, the clay must also stick firmly to the hearth wall and to the existing mushroom. In terms of materials properties, a high-performance taphole clay should present, respectively, a suitable plastic behavior and strong adhesiveness.[3] For this purpose, a specific deflocculant additive was developed and evaluated in this work. The additive was named as “XY” and it presents a structural configuration as shown in Fig. 3. The spherical shape of its main grains provides excellent injectability as a consequence of the efficient ball-bearing effect, which reduces the usual friction among the clay components as well.

Besides increasing the clay plasticity, the additive XY was designed in a way that its deterioration takes place in a wide temperature range, starting around 400°C and continuing up to 1,200°C. Such a disintegration process gradually generates transient liquid phases, which optimize the contact of the clay with the taphole and the mushroom surfaces, leading to strong adhesion properties.

Figure 4



Description of the fast heat treatment method.

In summary, by combining an optimized grain size distribution and an extremely efficient deflocculant additive, an entirely novel taphole clay technology was developed for building and keeping stable mushrooms and long taphole lengths.

Experimental Procedure

The new taphole clay composition (hereafter denoted as “new THM”) designed according to the innovative concepts previously described was comparatively evaluated with a standard composition (hereafter denoted as “standard THM”). Both new THM and standard THM presented the same overall chemical composition, differing only on the grain size distribution and on the presence of XY additive in the new THM formulation.

After performing the mixing step according to an internal mixing procedure, the samples of different shapes were prepared by uniaxial pressing. The open porosity and mechanical strength measurements were conducted after a fast heat treatment method (Fig. 4), which aimed to better simulate the actual conditions inside the taphole right after the clay has been pushed into the furnace. In this method, the unfired cylindrical samples (40 mm height x 40 mm diameter) were inserted directly into a pre-heated furnace at a desired temperature (400°C, 800°C or 1,000°C) and kept inside for either 20 or 40 minutes. After that period of time, the samples were withdrawn from the furnace and cooled down to room temperature. During the entire test, the samples are fully protected against any potential oxidation. After the fast heat treatment, the cold crushing strength (CCS) was measured according to ASTM C133-94 standard, whereas the open porosity was evaluated by using the Archimedes technique in water, following the ASTM C380 standard.

Hot modulus of rupture (HMoR) was carried out under three-point bending tests (ASTM C583) at 1,200°C and 1,400°C. For this test, prismatic samples (150 mm x 25 mm x 25 mm) were shaped, pre-fired, cooled at room temperature and then reheated for testing.

Corrosion tests were conducted in a rotary furnace, using unfired pressed samples. Depending on the test conditions, a different mix of blast furnace slag and pig iron was used:

- 80% slag + 20% pig iron for slag attack test.
- 20% slag + 80% pig iron for pig iron attack test.

Table 1 presents the chemical composition of the blast furnace slag used in the tests. The testing took place for 2 hours around 1,550°C and the slag + pig iron mix was changed every hour.

After the evaluation at lab scale, a pilot trial was conducted at two different blast furnaces in Brazil (A and B) in order to validate the better performance of new THM composition at actual conditions. Blast furnace A presents a daily production of 8,500 ton of pig iron and operates with four tapholes. Blast furnace No. 2 presents a daily production of 7,500 tons of pig iron and operates with only two tapholes.

Results and Discussion

Figs. 5 and 6 present, respectively, the open porosity and the cold crushing strength values of new THM and standard THM compositions after the fast heat treatment for 20 minutes and 40 minutes at 400°C, 800°C and 1,000°C.

In Fig. 5, it is possible to notice the positive effect of an optimized grain size distribution and the use of the newly designed deflocculant additive on the clay apparent porosity, mainly after 20 minutes, when the additive deterioration begins to take place. Due to a better packed structure and high bonding strength (as observed in Fig. 6), the usual high volume expansion and the consequent increased porosity at 400°C, originated by the volatiles' release, is restrained in the new THM. That proper balance between porosity and mechanical strength during the volatiles' release is essential to avoid crack generation and a poor corrosion resistance when in contact with the molten metal and slag.

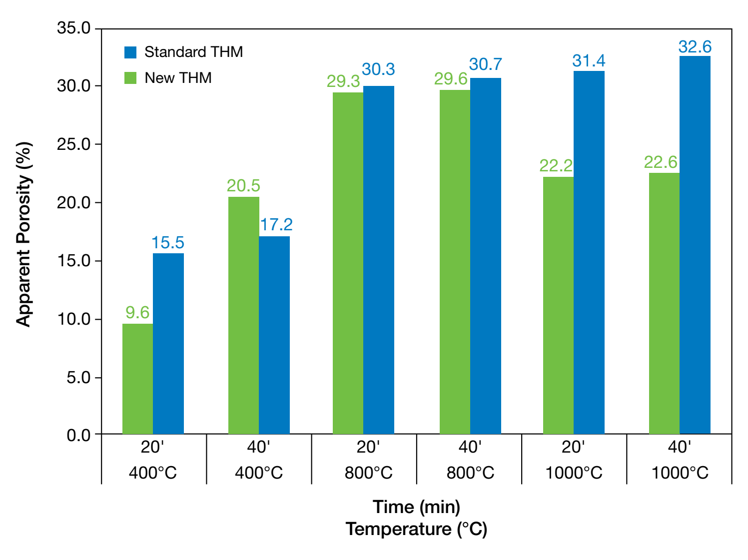
Although presenting open porosity and cold crushing strength results similar to the standard THM composition at 800°C, the improved performance of the new THM was again detected after firing at 1,000°C, in which the liquid phases generated during the XY additive deterioration played a very important role on speeding up the material's sintering process. For

Table 1

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

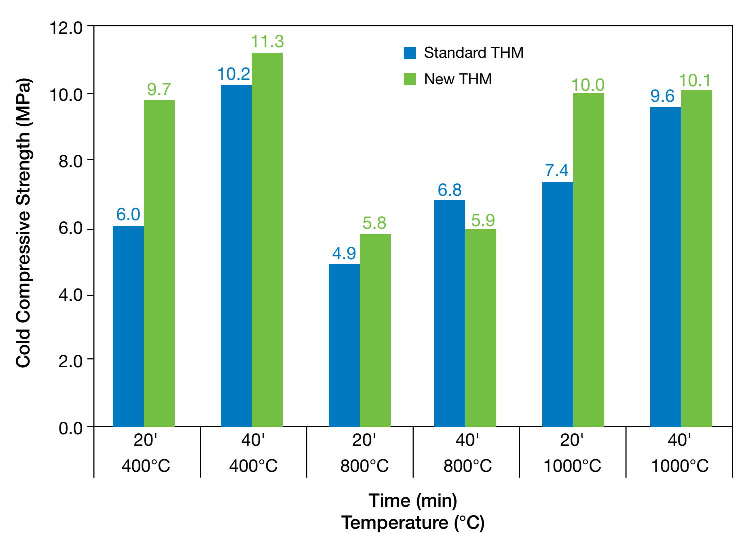
SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	MnO	Basicity B2
34.0	45.5	10.4	0.4	5.5	0.7	1.3

Figure 5



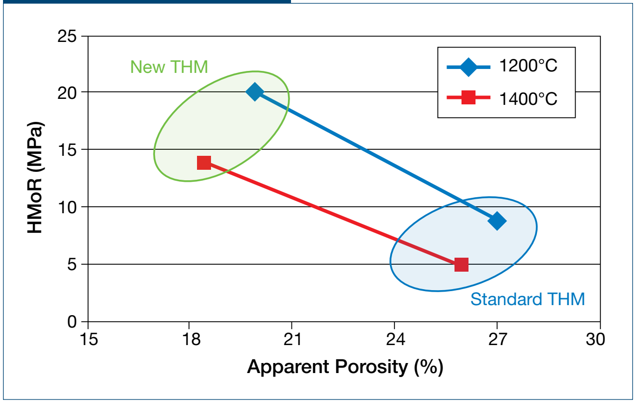
Open porosity of new THM and standard THM after heat treatment for 20 minutes and 40 minutes at 400°C, 800°C and 1,000°C.

Figure 6



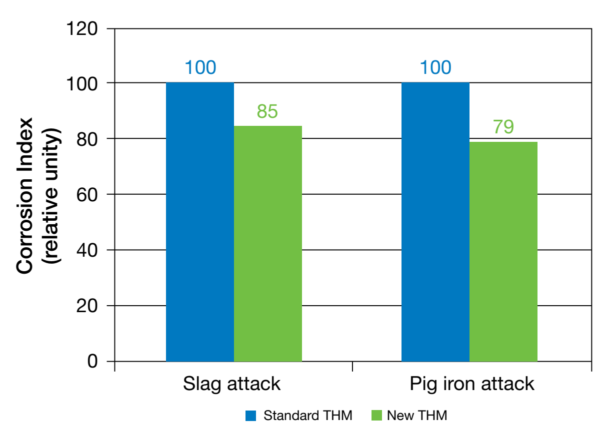
Cold crushing strength of new THM and standard THM after heat treatment for 20 minutes and 40 minutes at 400°C, 800°C and 1,000°C.

Figure 7



Hot modulus of rupture (HMoR) values for new THM and standard THM attained at 1,200°C and 1,400°C as a function of the materials' apparent porosity.

Figure 8



Corrosion index of new THM and standard THM compositions after the slag and pig iron attack tests.

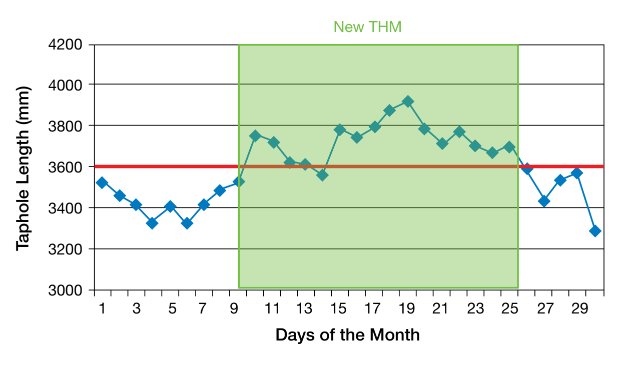
this reason, the apparent porosity values are more than 20% lower than the usual clay.

Fig. 7 shows the hot modulus of rupture values for new THM and standard THM attained at 1,200°C and 1,400°C as a function of the materials apparent porosity. The results confirm that the taphole clay developed with the novel technology is able to hold its enhanced performance at high temperatures as well. Not only could the effect of the lower porosity be noted by the high HMoR values, but also the fact that the transient liquid phase from the XY additive did not affect the new THM mechanical behavior at all. Such aspect is highly relevant, as low values of hot mechanical strength could easily decrease the material's erosion resistance to the aggressive pig iron peripheral flow.

Owing to such improved mechanical strength and to the proper grain size distribution, the new THM formulation presented a much better corrosion resistance to both slag and pig iron, as previously expected. Fig. 8 shows the corrosion index of the two compositions, measured after the slag and pig iron attack tests performed at lab scale.

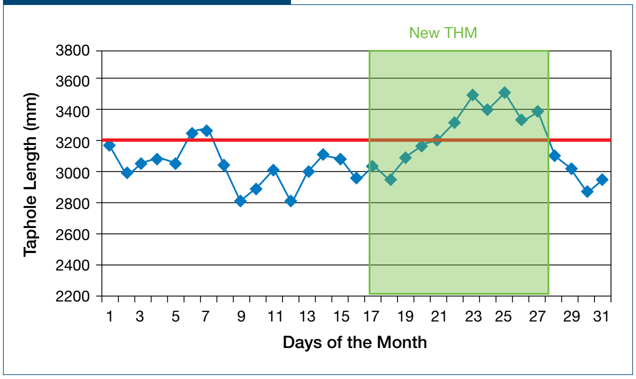
Based on the outstanding results attained at lab scales, two pilot batches were produced and sent for field trials at two different blast furnaces, which are here referred to as Blast Furnace A and Blast Furnace B. Figs. 9 and 10 presents the daily average values of taphole length measured during the trials at each furnace, where the green square highlights the period of time where the new THM was used. At Blast Furnace A, the performance of new THM was compared with the values attained with the standard THM, whereas at Blast Furnace B the reference for comparison was a material provided by another

Figure 9



Daily average values of taphole length obtained in Blast Furnace A. The green square highlights the period of time where the new THM was used and the red line shows the minimum value requested by the customer.

Figure 10



Daily average values of taphole length obtained in Blast Furnace B. The green square highlights the period of time where the new THM was used and the red line shows the minimum value requested by the customer.

taphole clay supplier, which was being used during the other days of the month.

On both graphs, one can easily observe that due to the current aggressive operative conditions in the Brazilian blast furnaces, both the standard THM and the material provided by another supplier were not able to provide the desired taphole length values. Right after the standard clay was changed to the new THM, long values of taphole length could be obtained, pointing out a fast mushroom recovering. Moreover, those high values remained for many days, mainly in Blast Furnace A (Fig. 9). After some days, the new THM was intentionally changed again to the standard THM (Fig. 9) or to the competitor material (Fig. 10) in order to check whether there was any other addition effect helping to keep those positive results. However, the taphole length values immediately dropped, indicating that the current technology widely used for taphole clay production is no longer attending the recent variations on the steel production process. A innovative solution based on different concepts, such as the high-performance new THM, proved to be the key answer to protect the blast furnace hearth and help to lengthen its working life.

Conclusions

In this work, entirely novel concepts of taphole clay production were proposed based on the optimization of grain size distribution and on the use of a special deflocculant additive. By combining those two mechanisms, a new THM formulation was designed, showing outstanding results at lab scale: tougher structure, controlled pores distribution, high mechanical strength at a wide temperature range and, consequently, a reduced corrosion index by both molten slag and pig iron.

Those excellent results could also be observed during the pilot trials at two different blast furnaces, where a fast mushroom buildup and stable values of taphole length were registered. Such high-performance material allows a blast furnace hearth to continue operating with a safe protection, enabling its working life to be lengthened by many years and consequently reducing the overall costs required for maintenance stoppages.

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This paper was presented at AISTech 2017 — The Iron & Steel Technology Conference and Exposition, Nashville, Tenn., USA, and published in the Conference Proceedings.