TAP HOLE FREE OPENING OPTIMIZATION IN THE EAF THROUGH MONITORIZED GRAIN SIZE DISTRIBUTION CONTROL OF THE EBT FILLER SAND. LABORATORY TESTING & INDUSTRIAL APPLICATION*

Esteban Ruisanchez Rodriguez[1]
Javier Martinez Rubio[2]

Abstract
In this paper we will discuss the process of the grain size customization of the EBT filler sand in relationship to the technical characteristics of the furnace and its tap hole. By customizing the grain size distribution, the glassy area formed on the top of the tap hole varies and supports differently the metallurgical pressure of the molten steel providing increased free opening speeds. Taylor made sand improves therefore the free opening rate, reduces the tap to tap time and increases the lifespan of the tap hole.
Keywords: Eccentric bottom tapping; Dunite; Filler sand; Innovative.

[1] *Mining Engineer, Business Development Manager, commercial department, Pasek Minerales SAU, Cariño, La Coruña, Spain.*
[2] *Mining Engineer, General Manager, management department, Pasek Minerales SAU, Cariño, La Coruña, Spain.*

1 INTRODUCTION

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PASEK is a Spanish company with over 40 years of experience in the steel sector and two business units: PASEK ESPAÑA (related to the refractory industry) and PASEK MINERALES (mining division). Within the scope of this second division, PASEK extracts and commercializes a rock called dunite from a mine located in the Spanish region of Galicia.
Over 25 million tonnes of dunite have been extracted from the beginning of the operation, with reserves exceeding 600 million tonnes.
Together with the EBT, the main applications of dunite are the following:

- Fluxing agent and slag conditioner in the Blast Furnace.
- Raw material for refractory products (with own refractory manufacturing facilities in Spain).
- Raw material on the rock wool manufacturing process.
- Others: construction sector, fertilizing industry, environmental applications…

In 2007 and in close collaboration with several steel plants in Spain, PASEK MINERALES commenced the evaluation of the use of dunite as EBT sand in replacement of existing materials. The product showed since the very beginning an outstanding behavior in this application, with excellent opening ratios and decreasing tap to tap times.
At the moment, PASEK MINERALES is selling EBT dunite to the largest steel groups in many countries: Spain, Germany, Belgium, Luxemburg, France, Morocco, Italy, United State…
This report describes the practical confirmation of the behavior of dunite as EBT sand, through the test carried out by Pasek Technical Centre (PTC) in collaboration with a world known research department. A technical description and thermodynamic conclusions are also presented.
From the mineralogical point of view, dunite is an ultramaphic rock with a basic chemical classification, being olivine and serpentine its principal components.

2 WORKING PRINCIPLE

After several years supplying the material as EBT sand in different markets all around the globe, PASEK decided to go one step further in the understanding of the working principle of the product.
It is for this purpose that PASEK Technical Department developed a replica of a standard Electric Arc Furnace tap hole, where same conditions than in a real tap hole were simulated.
Through this experiment we are now able to understand how dunite truly behaves inside the tap hole.

2.1 Dunite Behaviour

An efficient sealing in the upper part of the tap hole (Figure 1) demands sand with an accurate balance between mineral composition (which determines intragranular reaction), and melting point (which determines intergranular reaction) [e.g., 2].

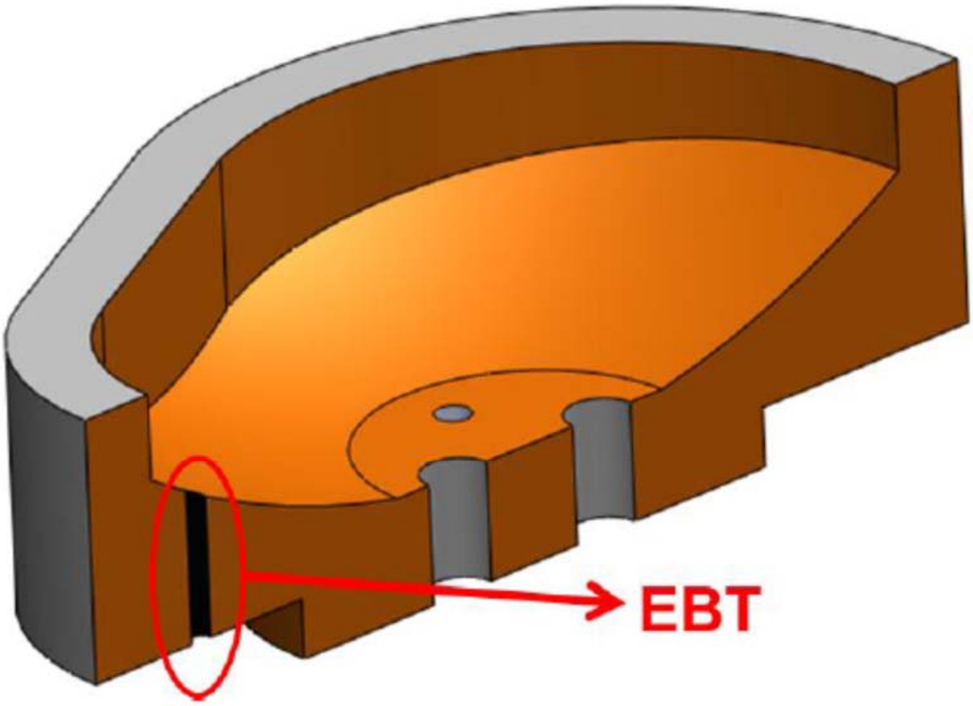

Figure 1. Eccentric Bottom Tap Hole (EBT) in EAF

Dunite effectively complies with these requirements [e.g.,1], showing some 1450ºC melting point and an extra-reactivity promoted by its complex mineralogy (see Figure 2).
Kinetic design of the dunite sand is carried out by a precise grain size distribution, usually either between 1 and 6mm or 3 and 6 mm. Calcined varieties of the product were also simulated.
The operational principle describes a thin layer of sealing material, in direct contact with molten steel which is supported by a body of sand grains. When the sliding gate in the bottom of the tap hole opens, raw sand falls into the ladle by gravity; right after, the steel ferrostatic pressure makes the steel break this sealing, running through the tap hole and falling into the ladle.

In order to investigate dunite behavior at the hot face in contact with molten steel, PTC technicians performed a scale test using a laboratory induction furnace in order to melt steel in a crucible with a scale tap hole filled with dunite sand.

3 EXPERIMENTAL PROCEDURE

3.1 Scale Tap Hole Design

Since the scale of the tap hole was to be changed, the real steel pressure over the hot area of molten sand needed to be kept. For this purpose, a 10kg induction furnace with a modified crucible (Figure 3) was prepared. The tap hole diameter and height were approximately one third of its "real" values.

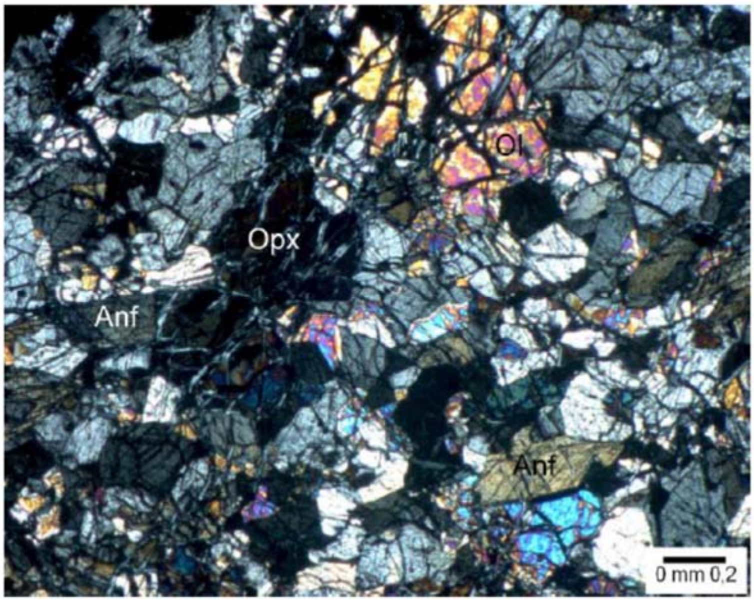

Figure 2. Micrograph (obtained by Polarizing Optical Microscope using transmitted light) showing the texture of dunite

In order to record the temperature gradient along the tap hole, four thermocouples were installed:

- First one at 350mm from the bottom – Hot area
- Second one at 250mm from the bottom – Medium area
- Third one at 150mm from the bottom – Cold area
- Forth one at the bottom – Slide gate area

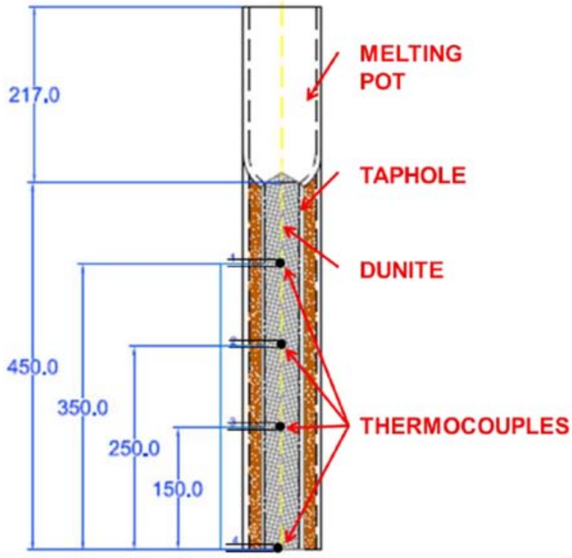

Figure 3. Test tap hole design.

The grain size distribution of dunite was reduced according to lab scale measurements. Further reduction would have affected the border grain adhesion above melting point, promoting unusual interface properties between molten steel and raw dunite.
The main objective of this work was the investigation of the mechanism of molten dunite interface, as well as the shape and thickness of this laboratory interface.

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3.2 Melting Experiment

The tap hole was filled with dunite and a propane flame preheated the crucible for 30 minutes.
After preheating, 10 kg of carbon steel were added to the crucible and inducted for 1 hour below steel melting point, in order to heat refractory crucible and dunite area in contact with steel. The complete melting of steel took 30 minutes after induction heating. The molten steel was then kept, promoting induction turbulence for 4 hours. Finally, the furnace was switched off and the tap hole was disassembled, in cold conditions, 24 hours later (Figure 4).

Figure 4. Induction test view.

The temperatures registered with the four thermocouples showed the gradient presented in Figure 5:

- TC1 increased up to 1200ºC and was then kept invariable
- TC2 went up to approximately 250ºC .
- TC3 showed same temperature level than TC4.
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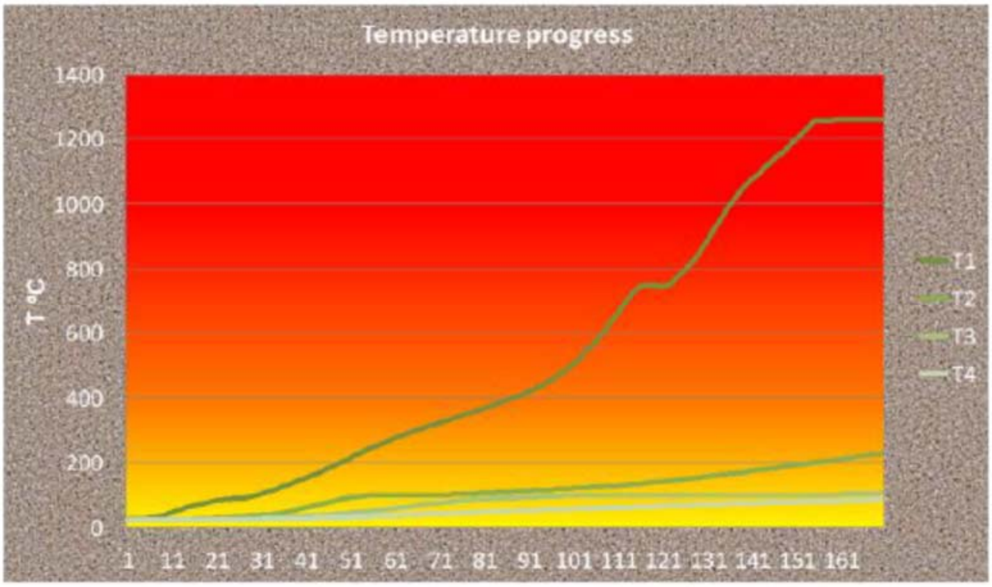

One point each 2 min. Total time 5 h 40 min.

Figure 5. Temperature gradient registered during whole test

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Some pictures of the cold crucible are presented in figure 6. The steel invaded the tap hole until the dunite sealing was effective. From TC1 level, 350mm from the bottom, raw dunite was recovered, according to the temperature profile. The sealing area was trapped by steel so it was necessary to mechanize it. Cut face picture is included in Figure 7.

Figure 6. Cold crucible after 24h

3.3 Sealing Mechanism

A thermodynamic analysis of this interface was performed by the petrologist team from the PTC.
It splits the sealing area in three zones:

- **Distal Zone**. Corresponding to the base of the sample, showing a dark green color, formed by welded EBT sand grains. No pores are visible.
- **Intermediate zone**. Including the majority of the sample, mainly in the central zone. Its color is dark green, but lighter than the distal zone, with some lighter colored patches. Pores are abundant and have round shapes and up to some millimeters in diameter.
- **Thermal shock zone**. It is a light-green colored area, 4 to 5 mm width band running along the contact border of the sample. Reflections of microscopic crystals are seen. These grains are mainly olivine. Porosity in this zone is similar or slightly lower than in the intermediate zone.

Figure 7. Interface steel-dunite

Under microscope, the 'distal zone' showed different individual grains; inside them, the natural texture and mineralogy of the dunite could be appreciated. This data indicates that the above area has not experienced temperatures above 500ºC.
On the other hand, the 'intermediate zone' analysis derives in identification of coarser olivine and pyroxene from original dunite, while the microcrystalline matrix was product of a solid-state reaction. This matrix is what causes dunite's sinterization, giving it a massive appearance. The microscope suggests that the temperature in the middle of this zone has overcome 800ºC.
Finally, the 'thermal shock zone', the sealed zone in direct contact with molten steel, is the one at a greater temperature, not far from the molten steel temperature. It is a continuous band, 4-5 mm in width, although it reaches 1 cm in the mass vertex. Mineral assemblage is almost totally olivine and small amounts of pyroxene and glass from partial melting. Olivine grains are cemented by a brownish to colorless isotropic material, which shows a glass-like behavior.

3.4 Correlationship with Real Process

The temperature in the tap hole and the refractory material in EAF hearth is much higher than the test temperature. This difference in thermal conditions does affect the melting time of dunite in the test, which is certainly higher than in real conditions.
In order to minimize this effect, dunite top layer was protected with a 2mm thick stainless steel piece,
with a limited tendency to induction, which would support molten steel a few minutes before the steel-dunite contact occurred. Even with this, the time of dunite melting was much higher than real.
In Figure 8, an extrapolation of dunite in a real EBT is proposed, based on the previous discussion. The high temperature on top of the tap hole starts to join grains of dunite.

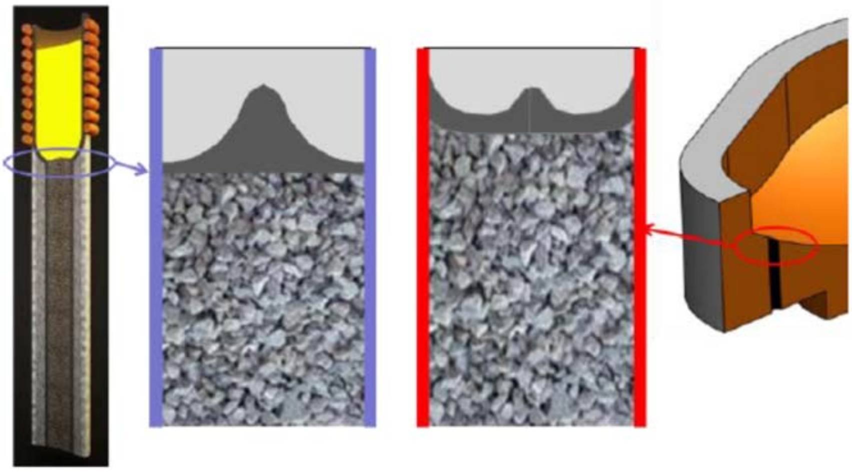

Figure 8. Comparison test vs real. Blue line represents cold tap hole (test) and red line represents hot tap hole (real).

4. CO-RELATIONSHIP OF EAF PARAMETERS AND GRAIN SIZE DISTRIBUTION

4.1 Parameters in EAF

The following parameters have an incidence on the tap hole sand behavior:

- Furnace temperature
- Stability of the temperature
- Geometry and dimensions of the furnace
- Furnace capacity
- Tap to tap time & stability
- Soaking plane
- Tap hole dimensions
- Tap hole filling method
- Amount of heats before tap hole reparation/substitution
- Tap hole cleaning frequency
- Gap between tap hole and sliding gate

4.2 Grain size Distribution of the Tap Hole Sand

The following grain sizes of the tap hole sand have been studied:

- 1-6 mm
- 3-6 mm
- Calcined 3-6 mm

They are compared on Figure 9, being the 3-6 mm and the Calcined 3-6 mm the same curve (3-6)

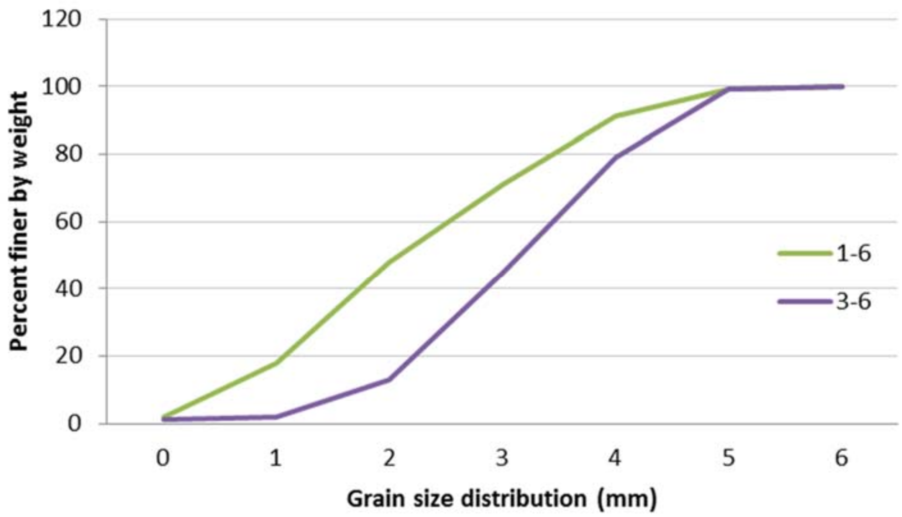

Figure 9. 1-6 and 3-6 grain size distributions

4.3 Relationship between EAF Parameters, Tap Hole Sand Grain Size Distributions

The optimum tap hole sand in function of the above mentioned EAF parameters is shown in Table 1:

Table 1. Effect of the EAF parameters on the tap hole sand

EAF PARAMETERS	1-6 mm	3-6 mm	Calcined 3-6 mm
Furnace temperature	> 1750 º	< 1750 º	>1600 º
Variations of the temperature	>7 %	< 7 %	> 3 %
Inclination of the furnace	> 5 %	< 5 %	> 3%
Furnace capacity	> 120 mt	< 120 mt	> 80 mt
Tap to tap	> 45 min	< 45 min	> 38 min
Variations of the tap to tap	> 15 %	< 15%	> 10 %
Soaking plane	> 40 min	< 40 min	> 25 min
Tap hole dimensions	< 200 mm	>200 mm	> 180 mm
Tap hole filling method	Manual	Hopper/neumatic/silo	Hopper/neumatic/silo
Number of heats of the tap hole before reparation / substitution	> 120	< 120	> 80
Tap hole cleaning frequency	< 1 per day	> 1 per day	> 1 per day
Separation between tap hole and sliding gate	< 10 mm	> 10 mm	> 10 mm

These are the analyzed parameters. Nevertheless, there are others which also have influence in the behavior of the glassy phase which may alter in some way the above empirical data.

4 CONCLUSION

- Dunite chemical composition allows an excellent intragranular reaction, which guarantees a proper closing of the hot face EBT.
- Some millimeters of fused dunite perform as contact inert layer with molten steel through a glassy phase, cemented by olivine crystals.

- Dunite melting point promotes proper intergranular joining, which is responsible of macroscopic growth of glassy dunite seal interface which retains molten steel.
- The so-called glassy phase created by dunite in contact with molten steel, offers the following benefits:

- Avoids molten steel propagation down the tap hole.
- Abrupt temperature drops along the tap hole.
- Shorten of time between tap to tap.

- Raw dunite below distal zone facilitates EBT opening and preserves mechanical elements from high temperatures.
- Test shows no reaction between raw dunite and steel due to inert glassy phase which is created.
- It shows an outstanding balance between safety of operation and opening rate.
- The election of the optimal grain size distribution is critical to obtain a great tap hole sand performance with time

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