INFLUENCE OF EBT SAND GRANULOMETRY ON THE FREE OPEN RATIO IN THE EAF

BY

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SYNOPSIS:

PASEK Minerales extracts and commercializes a rock called dunite from a mine located in the Spanish region of Galicia. Its chemical classification is basic, being olivine and serpentine its principal minerals.

The mineralogical composition and physico-mechanical properties makes Dunite PM is a suitable material for use as EBT filler sand in Electric Arc Furnaces. The working principle is based on the formation of a thin layer of fused dunite, in direct contact with the molten steel, which is supported by a body of sand grains. This sealing offers the following advantages: (i) avoids molten steel propagation down the tap hole; (ii) abrupt temperature drops along the tap hole; (iii) shorter times between tap to tap due to the fast free opening.

In order to offer an EBT sand adapted to each client, the company has carried out several projects to evaluate the behavior of the EBT sand during the casting process. In this way, Pasek Minerales has developed a simulation program based on the finite element method to determine the most suitable EBT sand according to a series of operating parameters of each customer (process temperature, dimensions of tap hole, type of sand...), with the aim of ensuring sand opening ratios higher than 97%.

Keywords: Dunite; EAF; EBT; tap hole; grain size.

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1. Introduction

PASEK MINERALES S.A.U. extracts and commercializes a rock called dunite from a mine located in the Spanish region of Galicia (image of the mine is shown in Figure 1). Dunite (magnesium silicate) is a plutonic rock formed by orthopyroxene, clinopyroxene and olivine in variable ratio. Different geological processes, mainly hydrothermal alterations caused by the contact with the seawater, have favored a secondary mineralization. It is a rock of basic nature and can be used both in its raw and calcined form, depending on the requirements of the applications for which it is intended.

The extraction and processing capacity of the dunite mine owned by Pasek Minerales is over 1 Mton per year. This is the largest magnesium silicate ore mine in Europe and since 1972, more than 27 Mton have been extracted, processed and commercialized.

![Figure 1. Spanish Dunite mine in Galicia.](image)

The physicochemical properties of Dunite PM are reported in Table 1. It should be noted the chemical composition (see Table 1a), which is based mostly on magnesium silicate, although other oxides such as Fe₂O₃ and Al₂O₃ are presented.

Among the physical properties, it is worth noting the possibility of tailoring the grain size and the value of its density, key factors compared to their competing products (olivine, for instance). In the tumbler test, olivine generates a sizeable amount of fine material, therefore it is not possible to have a wide range of mineral with varied granulometry. On the contrary, the grain size of Dunite PM can be adapted to the customer’s requirements since it displays high mechanical strength (shatter/impact/abrasion), so it does not generate fines by friction. Regards to packing density, dunite has a lower value than olivine (1.5 vs. 1.8 g cm⁻³), which is a positive point in applications where the product is used as a filler material, as is the case of EBT sand reported in this work.
Table 1. Mechanical, thermal and chemical properties of Dunite PM.

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgO</td>
<td>37.2</td>
</tr>
<tr>
<td>SiO₂</td>
<td>40.7</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>8.3</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>2.4</td>
</tr>
<tr>
<td>CaO</td>
<td>1.8</td>
</tr>
<tr>
<td>Na₂O + K₂O</td>
<td>&lt; 0.2</td>
</tr>
<tr>
<td>LOI</td>
<td>8.5</td>
</tr>
</tbody>
</table>

The EBT (Eccentric Bottom Tap Hole) system is the most used to carry out the slag extraction in EAF devices. The EBT enables the inclusion of nitrogen and slag to the steel flow to be minimized and tap-to-tap times to be reduced. It also decreases the consumption of refractory material and electrode, and improves the useful life of the ladle. The EBT of an electric arc furnace needs to be refilled from the top with sand after every tapping in order to seal it before starting the next melting process.

A remarkable number of steelmaking plants worldwide use Dunite PM to achieve the sealing of the EBT (steel mills in Spain, Germany, Belgium, Luxemburg, Italy, France, Morocco, United State...). The principle of operation consists in obtaining a stopper based on fused dunite, in direct contact with the molten steel, which is supported by a body of dunite grains that have been no sintered. This is a process of grain-to-grain fusion, so the grain size distribution is primordial. Once the treatment of the molten steel in the furnace has elapsed, the sliding gate in the bottom of the tap hole is opened. Thereafter, the ferrostatic pressure of the steel promotes the breaking of the sealed, causing the material to fall by gravity in the ladle, firstly the grains of dunite and subsequently the layer of sintered dunite in contact with the molten steel.

The physico-chemical properties and optimised grain size distribution of Dunite PM make it an efficient and low-cost substitute for other materials used for EBT sealing (i.e. magnesite). Taking this into account and with the aim of offering an EBT sand adapted to each client, in recent years Pasek Technical Centre (PTC) has carried out several projects to evaluate the
behaviour of dunite EBT sand during casting process. In this way, PTC has developed a simulation program based on the finite element method to determine the most suitable EBT sand according to a series of operating parameters characteristics of each customer (process temperature, dimensions of tap hole, presence of flat bath, etc.), with the purpose of ensuring free opening ratios higher than 97%.

In this report, we will show the petrographic analysis of Dunite PM, which allow to deepen the mechanism formation of the sealing, together with the results of the simulation of different kind of Dunite EBT sand, whose purpose is to design the EBT sand applied in each case achieving high opening ratios and avoiding filtrations of molten steel.

2. Exposure and discussion of results

One of the lab-scale tests carried out consisted in the simulation of a tap hole filled with Dunite EBT sand (SIMEBT project) and subjected to temperatures above 1600 ºC (the experiment was designed by equating to the pressure exerted by the steel flow on the EBT sand in a real tap hole). With this trial, it was possible to verify that the sealing consists of three different areas (see Figure 3).

![Image of meniscal of dunite in contact with steel](image.png)

Figure 3. Meniscal of dunite in contact with the steel (a). The same image with the zonation marked (b). The color has been exaggerated to better differentiate the regions.

The split of sealing area is as follows:

1. **Thermal shock zone**: Dunite melts with the steel and other compounds generating a sintering layer that plays as a stopper against the steel of the EAF, so filtrations are avoided. The formation of this sintering layer is due to a grain-to-grain fusion (these grains are mainly olivine) and its thickness is key to the suitable performance of the EBT sand. Reflections of microscopic crystals can be observed and the porosity degree in this area is similar or slightly lower than that of the intermediate region.

2. **Intermediate zone**: Most of the sample is included in this zone. Its color is dark green, but with some lighter colored patches. Pores are abundant and of round shapes, and can measure up to some millimeters.

3. **Distal zone**: Corresponding to the base of the sample, showing a dark green color. It is formed by welded EBT sand grain and there are no visible porosity.
The analysis of the sample with an optical microscope reveals that the “distal zone” is the one that displays the smaller transformation of dunite. Individual grains are observed and inside these grains, the natural texture and mineralogy of the dunite can be appreciated. This data indicates that the above area has not experienced temperatures above 500 °C. On the other hand, the “intermediate zone” analysis derives in the identification of coarser olivine and pyroxene from the original dunite, while the microcrystalline matrix was product of solid-state reactions of dehydration and recrystallization. This matrix justifies the sintering of the dunite, and gives it a massive appearance. The microscope suggests that the temperature in the middle of this region has overcome 800 °C. Finally, the “thermal shock zone”, the sealed zone in direct contact with the molten steel, is the one of a greater temperature, nearby to the melting temperature of the steel. It is a continuous band, 4-5 mm in width, although it reaches 1 cm in the vertex of the mass. The mineral assemblage is almost totally olivine and small amounts of pyroxene and glass resulting from partial melting. The olivine grains are cemented by a brownish to colorless isotropic material, which shows a glass-like behavior.

As a supporting to the microscopic observation, an approximate quantification of the porosity of dunite tested as EBT sand was performed using image analysis techniques. Although the calculations are approximate, the results reveal that the total porosity by the dehydration of the sample is around 22 % v/v. In addition, this porosity varies according to the zones, being maximum in the intermediate zone (both in size and quantity) and this tends to decrease in the zone of thermal shock, towards the contact with the steel.

The two most frequent problems that can arise with the opening of the EBT tap hole are, on the one hand, that the fried layer is too thick and with high degree of sintering, so the steel pressure is not enough to cause a free opening. In that case, it will be necessary to use oxygen lance to force the EBT tap hole opening, which means a delay in the productive process (products with high amount of fines). In the opposite case, when sand contains very large grain sizes, it may occur that the sealed zone is soft, leading to break through of the molten steel. To solvent these limitations, it is necessary to design a material with an optimal granulometry that generates free opening ratios of nearly 100 % with no break through.

The FEA (Finite Element Analysis) simulation has allowed us to design the most suitable EBT sand for each client. The grain size is adjustable taking into account the operating conditions of the oven (average temperatures and times of the casting processes), dimensions of the tap hole (diameter and depth) and physico-chemical characteristics of the sand (density, thermal conductivity, fusion point, etc.). The granulometry of the product will determine the thickness and sintering degree of the fried area.

Figure 4 corresponds to a simulation obtaining after applying the FEA, using Dunite EBT sand under three different operational conditions (varying temperature and casting time). It reveals how the thickness of the fried area is different in the three cases and data about the maximum thickness to produce spontaneous opening can also be extracted.
The products commercialized by Pasek Minerales as EBT sand have a grain size comprises between 1-6 mm. There are various Dunite EBT sands and they differ in the grain size distribution within such range. The granulometry is adjusted once the conditions of the process of the steel plant and the results of the simulation program are known. The combination of these analysis techniques makes Dunite EBT sand allows to ensure and excellent sealed, avoiding filtrations of liquid steel and with maximum percentages of free openings.

3. Conclusions

The physicochemical characteristics of Dunite PM determine its excellent behavior as EBT filler sand. The combination of several tools including a simulation program based on FEA, petrographic studies and other laboratory tests makes Pasek Minerales is able to commercialize a low-cost product with a granulometry adapted to each customer. Currently, Dunite EBT sand is being used in prestigious steel plants worldwide with an excellent yield (free-opening rates of 97%).