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From a mineralogical analytical view to a mechanism evaluation of cement kiln rings

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ABSTRACT

Ring growth in cement rotary kilns is a complex and a dynamic phenomenon, where the agents responsible for their formation cannot be easily controlled. This is reflected by the mineralogical heterogeneity of the deposit material. In this context, eight samples collected from two rings, formed in the same kiln, but at different periods (during 22 and 3 days), were subjected to qualitative and quantitative mineralogical study. The consolidation of these rings was the result of the combined deposition of the carbonates and the sulphates phases. The analyzes were focused mainly on spurrite $\text{Ca}_5(\text{SiO}_4)_2\text{CO}_3$, calcite CaCO_3 , sulfospurrite $\text{Ca}_5(\text{SiO}_4)_2(\text{SO}_4)$, Ca–Langbeinite $\text{K}_2\text{Ca}_2(\text{SO}_4)_3$ and chlorellestadite $\text{Ca}_{10}(\text{SiO}_4)_3(\text{SO}_4)_3\text{Cl}_2$. Their identifications and quantifications joined to the variation of sulfur amount and the calcination degree of the hot meal, permitted to better modulate the mechanism of ring formation in the kiln inlet.

1. Introduction

The coating formation on the rotary cement kilns walls is a critical phenomenon. The adhering material plays an essential role in the proper functioning of the entire operation. It protects the refractory lining from chemical attacks, thermal shocks and abrasion by the kiln bed, which enhances the reactor lifetime [1,2]. However, the thickness of the crust is not the same throughout the oven. It can reach very elevated heights in some areas and extend for some meters. Thus, this crusting is known as rings [3], which represents a frequent problem in the cement industry by generating an increase in energy consumption, a drop in the furnace production and, in extreme cases; it stops the kiln [1,2,4].

The chemical and mineralogical composition of the rings and their location in the furnace vary according to the process operating conditions. In reality, several agents interfere: kiln dimension, variation of the raw mix chemistry, fuel and heat combustion engineering and selection of refractory [1]. Besides, while the kiln is functioning, volatiles cycles stands; which is considered as an important cause that activates the rings' appearance [5]. The elements concerned are sulfur, potassium, sodium and chlorine. They originate from the raw materials and the fuel, and they circle throughout the system in repetitive evaporation–condensation cycles [6,7]. Cement makers adopt the ASR index ($\text{ASR} = (\text{Na} + \text{K})/(\text{2S}/\text{Cl})$) to estimate the composition of volatiles. Problems arise when the value falls outside the [0.8–1.2] range. Based on the chemistry formation, deposit materials are called sulfur rings when there is an excess of sulfur. If the opposite is true, they are called alkali rings. The sulfur excess is the most frequent and severe case [8,9]. Lastly, there is another type of ring known as spurrite ring.

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Therefore, the in-situ investigation of build-up and rings represents the first key to obtain data about how all parameters, which involved in the clinkering procedure, perform during the process. Few studies have investigated deposits that stick on the cement kiln walls, in order to predict the mechanisms that lead to the deposit formation. Indeed, ternesite $\text{Ca}_5(\text{SiO}_4)_2(\text{SO}_4)$ has been recognized as the main mineralogical phase, which is responsible for the material consolidation and the ring formation in the furnace upstream [4]. Other studies revealed the presence of spurrite $\text{Ca}_5(\text{SiO}_4)_2\text{CO}_3$ in ring formed in the pre-burning zone of a wet process cement kiln¹⁰ and the preheater system of short kilns [11,12].

In the present study, the issue under scrutiny is the mineralogical composition variation in cement kiln rings. The qualitative and quantitative analysis of the phases involved allowed us to estimate the mechanisms that govern the ring formation.

2. Experimental

2.1. Kiln characteristics

It is a full-dry kiln with a nominal flow rate of 4000 tons / day, length 83 m and internal diameters 5 m, 5.18 m, 5.80 m with four stages of cyclones and a grid cooler. Petroleum coke is the fuel used to generate the flame.

2.2. Sampling

The new kiln of the company “Les Ciments de Bizerte” has often developed rings. In this study, the interest has been focused on two rings that appeared in the kiln inlet. The first ring (A) formed after 22 days of service, with a maximum height of 62.5 cm and that extends from 53 m to 63 m of the furnace exit. After the total removal of the ring, a second ring (R) formed after 72 h of operation in the same position as A and with a maximum height of around 40 cm. Five samples were collected from ring (A) noted A1, A2, A3, A4 and A5 and three from ring (R) noted as R1, R2 and R3. The sampling was carried out in the brick-flame direction following the color variation of the build-up as illustrated in Fig.1. In addition, a hot meal sample was taken from the last cyclone of the preheater system and its corresponding raw mix.

2.3. Operating data

Table 1 gives the range of hot meal temperatures and the amount of O_2 (wt%) at the preheater exit as well as the oxygen quantity at the kiln inlet, during the period associated to the formation of each ring. The Lime Saturation Factor (LSF), Silica Ratio (SR) and Alumina Ratio (AR), characteristics of the raw powder, are also given.

Fig. 2 shows the variation of the calcination degree, related to the raw meal entering the kiln, during the period preceding the ring formation. From this data, it is clear that the raw powder, which entered the kiln, was characterized by a non-stable decarbonation rate.

2.4. Analytical techniques

The chemical composition was determined via X-ray fluorescence and for the mineralogical investigation, XRD patterns of different samples were recorded by an ARL 9900 diffractometer operating with monochromated $\text{Co K}\alpha 1$ radiation (1.788996 Å). Later, a Rietveld method was applied on all samples, using X'Pert High Score plus, to estimate their mineralogical composition in percentage by weight (QXRD). A thermogravimetric (TGA) analysis was performed using “Setaram Setsys” equipment with a heating rate of 10 °C/min in an inert atmosphere for five samples (A1, A3 A5, R1 and R2).

3. Results

3.1. Chemical composition

There is a noticeable concentration of sulfur and alkali (Table 2) as volatile elements compared to those introduced in the raw meal, which is a sign of the high activity of volatile cycles in the kiln inlet. Sulfur and potassium levels fluctuate significantly between [3.68–9.84] for ring A and [4.78–7.47] for ring R. Yet, Na_2O seems stable in both rings.

3.2. XRD results

A typical XRD profile of heat meal is given in Fig.3. It shows that the major phases, entering into the kiln inlet, were the free lime, the calcite and chlorellestadite. Quartz and C_2S also existed in considerable amounts. As minor phases, there were magnesite, spurrite and sulfo-spurrite. In addition, the sample contained a trace of sulfated compounds such as arcanite K_2SO_4 and $\text{K}_2\text{Ca}_2(\text{SO}_4)_3$.

The X-ray diffraction analysis (Figs.4 and 5) revealed the notable heterogeneity of the different samples removed from the two rings. Indeed, they contain the main clinker phases including alite (Ca_3SiO_5), belite (Ca_2SiO_4), aluminates and Brownmillerite. Carbonated phases, especially, calcite CaCO_3 and spurrite $\text{Ca}_5(\text{SiO}_4)_2\text{CO}_3$ and even magnesite MgCO_3 . The XRD has permitted the detection of different sulfated phases: chlorellestadite $\text{Ca}_{10}(\text{SiO}_4)_3(\text{SO}_4)_3\text{Cl}_2$ is present in all samples, the ternesite $\text{Ca}_5(\text{SiO}_4)_2(\text{SO}_4)$, and Ca-langbeinite $\text{K}_2\text{Ca}_2(\text{SO}_4)_3$ are absent in sample A1. Portlandite $\text{Ca}(\text{OH})_2$ was formed, most likely, from the free lime during the

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