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Influence of gypsum's mineralogical characteristics on its grinding behaviour applied to cement fabrication[1]

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Abstract

In an industrial process of cement fabrication, the use of mixtures of 95% clinker and 5% gypsum with two different kinds of gypsum (similar chemical composition but different source) results in grinding power consumption differences up to 15%. The mentioned differences are not explained when performing power consumption evaluations according to Bond's method. On the other hand, studies of both gypsums by means of transparency microscopy show their differences in textural characteristics and lead to the explanation of such a behaviour difference, as much in grinding in the industrial process as in the laboratory tests. The transparency microscopy continues being a recommended tool in the selection of appropriate raw materials in the cement industry.

Keywords: Gypsum; Cement; Clinker; Transparency microscopy; Grinding; Work index

Gypsum is added to clinker in grinding at the end of the fabrication process to control the hardening velocity of the cement. In an industrial process of cement fabrication, the change of a "gypsum 1" (Fig. 1) to a "gypsum 2" (Fig. 2), both of similar chemical composition but different sources, involve variations up to 15% of energy consumption in the grinding process when gypsum added to clinker is only 5%.

First, it seems logical to think that there is a different grinding aptitude between both gypsums, which leads to different work indices in each case. But it can also be observed that during grinding in plant, gypsum adheres as a covering of the mill balls. This fact could explain the mentioned differences in energy consumption.

With the aim of analyzing the reasons for these differences, two complementary techniques have been applied:

- Determination of the "work index" by means of typified tests of grinding for the different products.
- Mineralogical studies of both gypsum feed stocks.

As follows, the results obtained are exposed. They are correlated with data corresponding to industrial plant and it is analysed how these techniques of study can be useful in an industrial process, as much in their role of control system for the process as for selection and quality control for raw materials (gypsum, in this case).

1. Experimental methods

1.1. The different gypsums used

Gypsum 1 is from an ore deposit located near the cement factory. This gypsum has been traditionally used in the process without problem, and its substitution is motivated by depletion of ore reserves. Gypsum 2, which has been used for this research, is from a deposit located in another area with different characteristics (geological age, geological setting, etc.).

The control of material is made inside the plant by means of routine chemical tests, which do not demonstrate any significant differences between the two types of gypsum. However, the use of gypsum 2 was bound to higher energy consumption than the use of gypsum 1 at the final grinding stage. This difference in consumption can reach up to 15%, even with processes in which the final grinding is done with mixtures of 95% clinker and 5% gypsum.

1.2. Study of work index

The tests to determining energy consumption indices were carried out following the methodology proposed by Bond [1,2], with the only difference being that the mill used has half the volume proposed by Bond. Due to this fact nec-

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Fig. 1. Gypsum 1, with predominant sedimentary structures. It can be seen that some fragments have a brecciated aspect.

essary corrections have been made to the weight of the balls and weight of the sample, so as to have enough accuracy in the estimation of the Bond index. Despite possible differences among calculated work indices and Bond indices in those materials, the calculated values can be used to establish a comparison between energy consumption levels.

The results obtained in the mentioned process are presented in Table 1. Testing was conducted of samples of clinker, gypsum 1, gypsum 2, and mixtures of clinker with each of the gypsum types, in quantities of 5 and 20% gypsum content by weight.

The analysis of the results shows that the values do not correlate with the results obtained in the industrial practice. It was observed that in the industrial practice the addition of gypsum 2 in the clinker grinding leads to a noticeably higher power consumption than in the case of gypsum 1. However, the results of the work index tests give gypsum 2 the value of 3,99 kWh/t, lower than the one obtained for gypsum 1 (11,48 kWh/t). In the case of mixtures, the differences observed are very low, but in the case of 20% gypsum, the lower values are still obtained with gypsum 2.

As consequence, using only the determination of the work index is considered to be an inadequate method to resolve the proposed problem. In this case, differences in energy consumption in plant are not only conditioned by mechanical properties of gypsum's breaking resistance. It must be concluded that there are other determinant factors during the industrial grinding process.

Fig. 2. Gypsum 2. Massive gypsum with greater crystal size than in Figure 1.

Table 1
Calculated work indices for the testing materials

Sample	Work index (kWh/t)
Clinker	17,92
Gypsum 1	11,48
Gypsum 2	3,99
Clinker (95%) + gypsum 1 (5%)	17,45
Clinker (80%) + gypsum 1 (20%)	18,17
Clinker (95%) + gypsum 2 (5%)	18,14
Clinker (80%) + gypsum 2 (20%)	17,93

1.3. Data of significance to be considered for subsequent discussions

1. For the determination of the work index, a dry grinding was used with a cut sieve of 100 μm because dry sieving with sizes <100 μm leads to significant errors due to agglomerating effects of moisture and electrostatic charges between particles.
2. At an industrial level, the final grinding of clinker and gypsum produces a commercial cement with a 70% or more in the 3–30-μm range.

1.4. Mineralogical study

Mineralogical investigations were conducted using transmitted light microscopy and X-ray diffraction.

1.4.1. Mineralogy

Results indicate that the two gypsum feed stocks are of similar mineralogical composition. In fact, both prove to be mixtures of gypsum and anhydrite with low quantities of clay minerals. According to data from chemical analysis, both gypsum feed stocks may be considered as similar products. Except for minor variations between hand samples, the mineralogy of both feed stocks is without practical significant variance. No

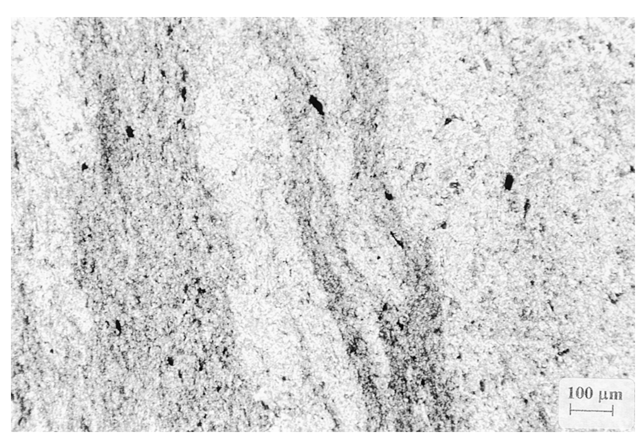

Fig. 3. Gypsum 1. Microscopic view showing a very fine grain size and laminations with a greater content in clay and carbonaceous materials than in Figure 2.

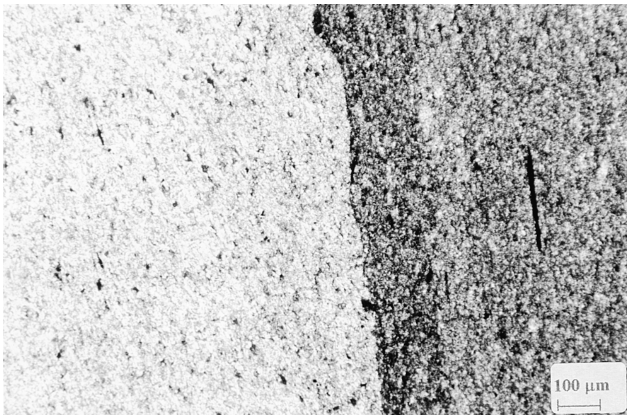

Fig. 4. Gypsum 1. Microscopic view analogous to Figure 3.

chemical or mineralogical variance was identified to justify the observed variations in amount of grinding required.

1.4.2. Texture

The textural difference between both gypsum types is considered very important. Gypsum 1 shows for the most part a very fine grain texture where gypsum crystals have a very solid packing with the absence of exfoliation surfaces (Figs. 3, 4, 5, and 6). On the other hand, gypsum 2 has a larger grain size with a very pronounced presence of abundant exfoliation surfaces (Figs. 7, 8, 9, 10).

In gypsum 1 there is a strong packing of sulphate crystals with very fine and nonoriented intergranular surfaces, which are not sutured (Figs. 3 and 5). Instead, gypsum 2, besides being characterised by big crystals of sulphate, has very well-developed exfoliation systems (Figs. 8 and 10).

These textural differences serve to justify the following:

- Results of greater energy consumption in the grinding plant when gypsum 2 is used.
- Results, seemingly contradictory, of tests carried out to obtain the work index.

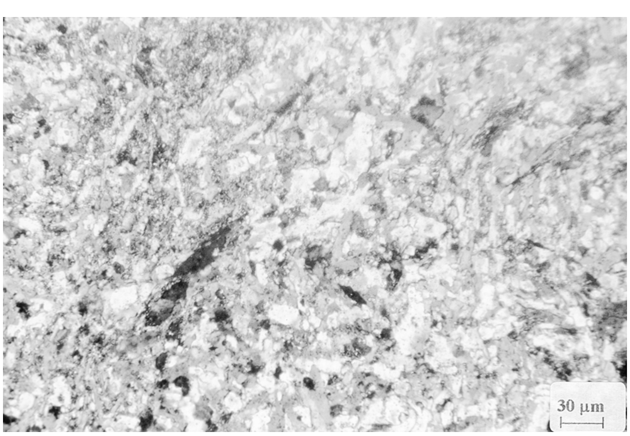

Fig. 5. Gypsum 1. Microscopic view of gypsum with fine grain almost totally replacing anhydrite.

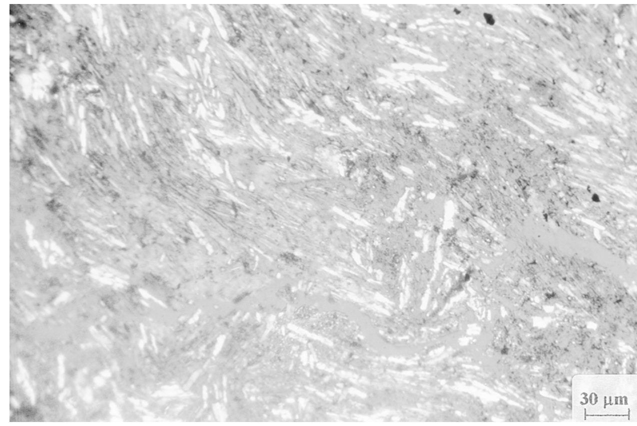

Fig. 6. Gypsum 1. Replacement by gypsum of needle-type anhydrite.

2. Discussion

2.1. Differences in work index

1. The network of exfoliation surfaces in crystals of gypsum 2 facilitates the rupture in the gross grinding stages, as is the case of tests to obtain the work index (cutting at 100 µm), since it makes use of these surfaces. Also, it will produce an easy rupture using the big intercrystalline surfaces.
2. In gypsum 1, because the size of monocrystalline grains is <100 µm, the rupture will be predominantly transcrystalline with scarce rupture according to the network of intergranular surfaces, which have an average dimension <100 µm.

In conclusion, in this case the obtained work index results are reasonable. They are representative of gross grinding and could be applied only to determine energy consumption in the initial phases of the industrial grinding process.

2.2. Differences of energy consumption in industrial grinding processes

The 3–30 µm fraction in a regular cement is usually about 50%, and in certain cases exceeds 70%. In the case of

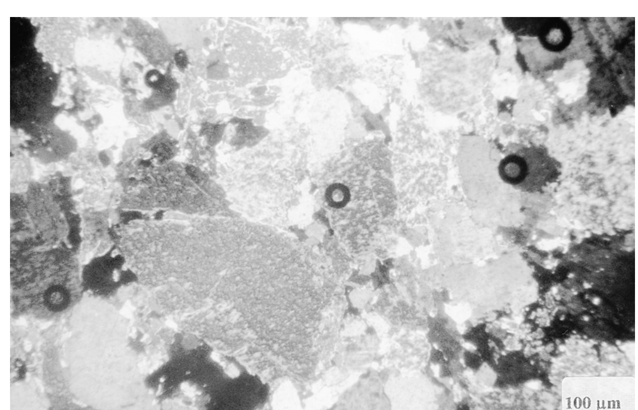

Fig. 7. Gypsum 2. Predominance of big grain size. Gypsum replaces anhydrite.

Fig. 8. Gypsum 2. Gypsum replaces anhydrite; both show big grain sizes and marked cleavage systems.

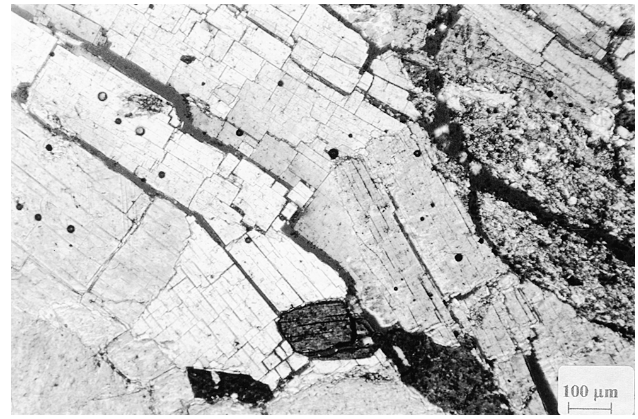

Fig. 10. Gypsum 2. Big grains of gypsum and anhydrite. The strong cleavage makes breakage easier.

gypsum 1 with a high proportion of crystals in that size interval (Figs. 2, 3, and 4), the rupture in industrial grinding occurs using a great deal of the discontinuities in the intergranular surfaces. On the other hand, for grinding gypsum 2 with large crystals, 3–30 μm particles will be formed with a great proportion of their surfaces constituted by intracrystalline rupture surfaces (Figs. 7, 8, 9, and 10).

In this second case, the calcium sulphate particles will have, logically, a greater surface electric charge, giving origin to more intense adherence phenomena between particles, and between particles and the metallic elements of the mill (balls).

With gypsum 2 there will be a major “film effect” on the milling elements and, consequently, it will produce a greater muffling of the impact of the balls, which leads to higher energy consumption. This effect is more critical as the grinding progresses and the gypsum particles become smaller.

3. Conclusions

1. The textural characteristics of gypsum justify the different behaviours in grinding of the respective mixtures of gypsum with clinker at the end of the cement fabrication process. Logically, for similar mineralogical composition, the gypsum more suitable for the process must have fine grain textures, while coarse-grained gypsum facilitates the film effect and will cause more energy consumption.
2. The great differences in the work index between both gypsum types may be explained as due to the grain size and the presence of exfoliation systems. When grain sizes are smaller, we may hope for higher work index values. For similar grain sizes, the presence of exfoliation systems give origin to lower work index values.
3. In an industrial process such as the grinding of clinker, the work index alone does not serve to characterize grinding processes with mixtures of gypsum and clinker when that index is obtained with cut sizes >100 μm. The reason is that the film effect is not produced when determining the work index with the intensity observed in the industrial process of cement grinding, which reaches $>70\%$ in the output proportions of the granulometric fraction 3/30 μm.
4. When it is necessary to use gypsum 2, it seems evident that the use of grinding additives will be necessary to remove or attenuate the film effect. These additives that serve to neutralize the superficial charge of particles and to avoid the film effect in grinding are found on the market and they are used by the cement industry. Their main trouble is the increasing costs of the process.
5. It seems to be evident that the convenience of introducing mineralogical analysis, especially textural studies, in the selection and control of gypsum for its use in the cement industry is warranted, since a simple control by chemical analysis has been shown here to be insufficient. For this analysis, the use of transmitted light microscopy for the study of thin sections will be the most useful tool.

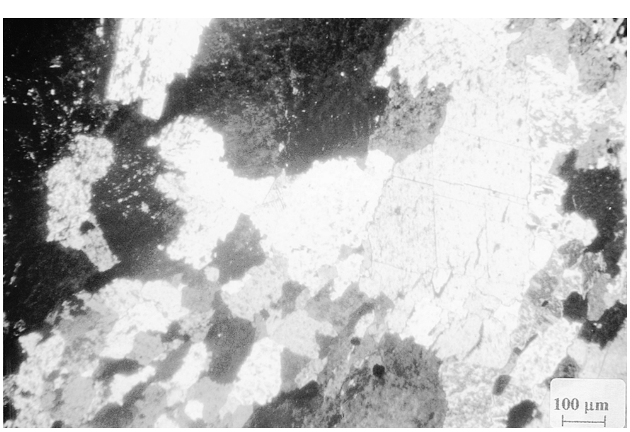

Fig. 9. Gypsum 2. Gypsum with rest of anhydrite. The gypsum shows a pronounced cleavage.

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