GRINDING ABILITY OF UNPROCESSED AND PROCESSED CLINKER FROM CEMENT INDUSTRY

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This article is intended to describe the main grinding and hardening methods used in the cement industry. These methods are widely used in the cement industry for several reasons: the sizing of new plants and improving existing grinding plants in cement plants.

Keywords: cement factory, grinding systems, ball mill, grinding ability, fineness of the material, residue, specific energy, energy efficiency

1. Introduction

In the last period, a new concept of clinker grinding has emerged, which achieves a reduction in electricity consumption. The process consists of passing the clinker through a roller mill that works at high pressure and acts on a layer of clinker. This process cannot be confused with the crushing of the clinker, which does nothing but reduces the size of the granules larger than the size for which the grinding machine operation is optimal.

In addition to crushing the material, the high pressure also produces a process of cracking the granules, regardless of their size, throughout their mass.

In the current state of the art, the grinding operations in the cement industry and the laboratory ones are performed by mechanical methods, transmitting to the granules the forces necessary for their crushing with the help of the grinding organs. The grinding process's kinetics results from the effects of two phenomena with opposite tendencies: the crushing of the granules and their agglomeration.

The ability of materials to crush (break) is characterized by a series of parameters highlighted by slow compression tests on individual granules in laboratory presses. These parameters are determined by the specific breaking stress (N / mm^2) and the specific crushing energy (J/g; kWh/t) [1].

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Agglomeration is characterized by the proportion of agglomerated material during crushing in a roller mill.

Grinding has been expressed in different ways. For example, the energy consumed in grinding for a certain fineness (kJ / kg) or the specific surface area (kJ/ m^2). It can also be expressed by the specific area formed in the time unit (m^2 / kg min) and even the Bond index relative to the area unit (J / m^2) [2].

Larger particles tend to disintegrate earlier in the grinding process and consume less energy. The difference in the decrease rate in particle size from different materials can be explained by the differences between their mechanical properties [3]. During grinding, external forces are applied to overcome the cohesive forces between the molecules of the material being ground. This causes the particles to be disturbed, resulting in their disintegration and an increase in the total specific surface area. Due to cracks and inhomogeneous surfaces, the technical strength is much smaller than the theoretical molecular strength. Therefore, the individual particles disintegrate during grinding in areas of low strength. When the particle size is further reduced, the number of these areas gradually decreases, and this increases their resistance to subsequent disintegration. This is one of the main causes of the high consumption of specific energy in grinding fine particles [4-7].

In order to characterize the behavior of the materials subjected to crushing, a synthetic parameter is used, called grinding ability, determined by laboratory tests performed with devices, mainly similar to industrial mills.

Among the numerous procedures for determining the grinding ability, elaborated by different authors and used internationally (Hardgrove, Mittag, Zeisel, and Bond) [8], there is also the CEPROCIM procedure used in Romania.

Cement grinding is an important topic when it comes to energy consumption. Clinker grinding is responsible for about 40% of total energy consumption during cement production [9]. Therefore, grinding is a potential way to save a considerable amount of energy, as some mineral mixtures have a clear positive influence on the grinding ability of the clinker.

The Bond method is the most commonly used. Unlike other previous methods, it uses a ball mill with a diameter and length of 305 mm, which is filled with a number of grinding balls with different diameters. The material to be ground must have a particle size of less than 3.35 mm [10].

The aim is to find the correct number of rotations to obtain a specific ratio of oversized particles (larger particles) and undersized particle (smaller particles) on the 106 µm sieve. The result is expressed in kWh/t, and the values reach 6–9 for well-grinded materials and over 20 for poorly grinded materials [10].

When discussing the influence of clinker grinding, we must always take into account the chemical and physical properties of the materials to be grinded, the grinding time, the desired fineness or energy consumption, and the grinding equipment.

The chemical composition and manufacturing conditions have an influence on the grinding process. For example, M. Tokyay [11] conducted a study on 15 types of clinker that have a wide range of chemical compositions. He found that Al_2O_3 and free Al_2O_3 content CaO content, silicon modulus (SM), liquid phase (Lp), and the ratio between silicates and fluxes [(C_3S + C_2S) / (C_3A + C_4AF)] influenced the grinding ability. Another example is the beneficial effect of the beneficial influence of rapid cooling on grinding [12].

Clinker grinding can be influenced by adding metal oxides or calcium sulfate of metal oxides or calcium sulfate to raw mix [13,14]. They control the oven's melt content and the clinker's porosity.

Regarding the final grinding of the cement, all the grinding steps are decisive for producing a necessary Blaine surface (3500 cm^2 / g). Therefore, the choice of ball size according to a maximum specific selection function increases energy consumption. In addition, investigations of one-dimensional fractions and crude fractions, the raw material (size <2.8 mm) show that the energy efficiency factor can be optimized by using the ball size corresponding to a relatively low specific selection function [15]. The use of cement clinker grinding additives (as plasticizer additives; fluidizing additives; water reducing additives; air entraining additives; hydrophobic additives; antifreeze additives; hardening accelerator additives; setting and strengthening accelerator additives; setting retarding additives; corrosion inhibitor additives); it may be convenient in today's growing demand for materials. Along with the need to process increasing quantities of ores containing finely dispersed minerals, our limited energy resources and rising energy costs are challenging for the process engineer. One way of research that has been explored for about half a century is the development of mill feed additives that substantially improve grinding efficiency. Such additives are called grinding aids [16].

The properties and performance of mixed cements are influenced by the proportions and reactivity of mineral additives but also, to a large extent, by the dimensional distribution of the particles. Using additives is one of the most cost-effective ways of reducing the specific power consumption at grinding. The different components of the mixed cement must each obtain a certain fineness in order to be hydraulically, latently hydraulically, or pozzolanic effective [17, 18]. There are various methods for determining the particle size distribution, each of which gives different results [19].

Clinker grinding is a step in making cement that consumes about a third of the electricity needed to produce a ton of cement. This refers to an average specific power of 57 kWh/t [20, 21].

The paper analyzes the influence of the pressure on the clinker structure, the particle size structure, and the electricity consumption during grinding, in the laboratory mill type CEPROCIM SA.

2. Materials and Methods

In the experimental determinations of this paper, clinker from one of the cement factories in Romania was used to determine the grinding ability in: laboratory mill type CEPROCIM S.A. (fig.1) [22];

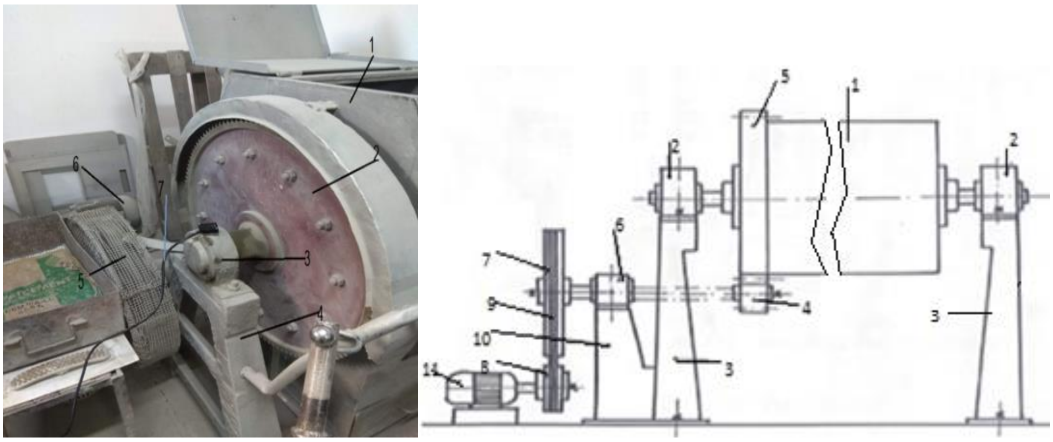

Fig.1. Laboratory Ball mill (view and scheme) [22]
1. body mill; 2. milling bearings; 3. mill supports; 4. attack sprocket; 5. toothed crown; 6. bearing of attack sprocket; 7,8.wheel belt; 9. trapezoidal belts; 10. bearing support for attack sprocket; 11. electric motor

In order to highlight the influence of the pressure on the structure and granulometry of the clinker, its grinding ability was determined (in the two specified laboratory installations) on standard clinker samples (unpressed) and on pressed clinker samples.

The second one, the ZD 10/90 press was used for slow compression stress which was achieved by applying a force to a material, in our case clinker. The strengt is defined as the maximum load supported divided by the average cross-sectional area. The load was applied to the sample until the clinker was pressed to 20 Mpa and 100 Mpa, respectively.

The ZD-10/90 press is equipped with a measuring system that allows:

- manual control of the loading process;
- electromechanical load generation system;
- visualization of the real and maximum value of the load on the analog dial;
- automatic maintenance of the loading rate;
- recording of test parameters - recorder with two coordinates with auto-recording;
- tensometric load measurement sensor;
- high rigidity of the power frame.

The material to be ground in the 2 installations must have an initial particle size of the material between 0-7 mm, according to the methodology for determining the grinding ability.

2.1. Determination of grinding ability by CEPROCIM process

The process is based on grinding a batch of material, the size of the load being introduced into the mill depending on the mass of the material in question and the useful volume of the mill. The materials to be grinded are pre-grinded to a size <7 mm (eg with a Retsch BB 100 jaw crusher).

The mass of this material (<7 mm) is determined.

The amount of material introduced into the mill is equal to the mass (kg / l) reported to the volume of the gaps between the balls that form the mill load (liters). For the mill used at CEPROCIM, the volume of the gaps calculated according to the degree of loading and the density of the grinding bodies can be considered 12 liters.

The grinding of a batch of material (clinker) in the laboratory mill (ball mill type) with a horizontal rotating drum was carried out in two stages: first stage using ball load (see table 1); the second stage using a load of biconical bodies (ø 25-30 mm) - 137.77 kg up to an imposed fineness, expressed by the residue R_{009} or by the specific Blaine surface area (cm^2 / g).

The fineness of the material (residue R_{009}) was periodically determined and the energy consumption was recorded using a meter. These consumptions were cumulated from the beginning of the determination and were related to the mass of the charge, calculating the specific energy consumption. The first stage is considered complete when R_{009} is ~ 35%.

Taking as an example the grinding ability of a clinker sample, the fineness of grinding (specific Blaine surface area) in relation to the specific consumption of electricity is presented graphically as follows (fig.2).

CEPROCIM grinding aptitude indices are represented by the specific electricity consumption corresponding to a certain reference fineness (usually for raw materials R_{009} = 10%, and for cement the specific Blaine surface area = 2500 cm^2 / g) [1]. For this reference fineness, the specific energy consumption *w* of the industrial mills at the engine power supply connection is determined. Under these conditions, *w* includes in addition to the actual mill consumption and engine and transmission losses.

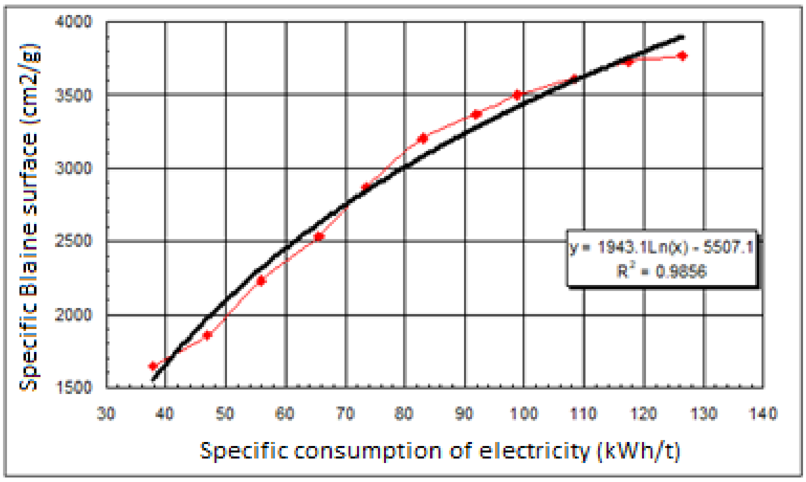

Fig.2. The fineness of grinding in relation to the specific consumption of electricity

The grinding ability index is represented by the specific energy consumption w_1 corresponding to a fineness of reference [1]:

$$c_1 = \frac{w}{w_1} \tag{1}$$

where: w - the specific energy consumption of the industrial mill, in the case of actuation by final gear sprocket-gear unit and speed reducer, including losses from the electric motor; c_1 - correlation coefficient with industrial mills.

3. Results

3.1. *Determination of grinding ability with CEPROCIM laboratory mill*

Grinding was performed in the laboratory mill (fig.1), without recirculation, belonging to CEPROCIM S.A. The load with grinding bodies, for this experiment in the first stage of grinding (coarse) was:

Table 1

The load of the grinding bodies

Ø [mm] grinding balls	65-75	55-65	45-55	Total
G [kg] grinding balls	73.47	36.75	27.77	~137.77

In the second stage, with a structure of the grinding load with dual cones ϕ25x30 mm and their mass ~137.77 kg, the granulometry of the material, when feeding the mill, was between 0-7 mm, according to the CEPROCIM methodology. For laboratory experiments 11 batches of clinker were prepared, as follows:

- sample (batch) 1 - standard clinker whose particle size distribution is shown in Table 2:

Table 2

Particle size distribution of standard clinker and pressed clinker (20 MPa)

Sieve apertures, mm	Clinker standard, %		Pressed clinker, %	
	partial	cumulative	partial	cumulative
25	8	-	5	-
15	21	8	15	5
10	8	29	16	20
7	11	37	14	36
5	22	48	10	50
3	12	70	11	60
1	9	82	11	71
<1	9	91	18	82
	-	100	-	100

- samples (batches) 2–9 - clinker pressed at a pressure of 20 MPa whose particle size distribution after pressing is that of table 2 and fig.3. A ZD 10/90 press was used for the slow compression load.

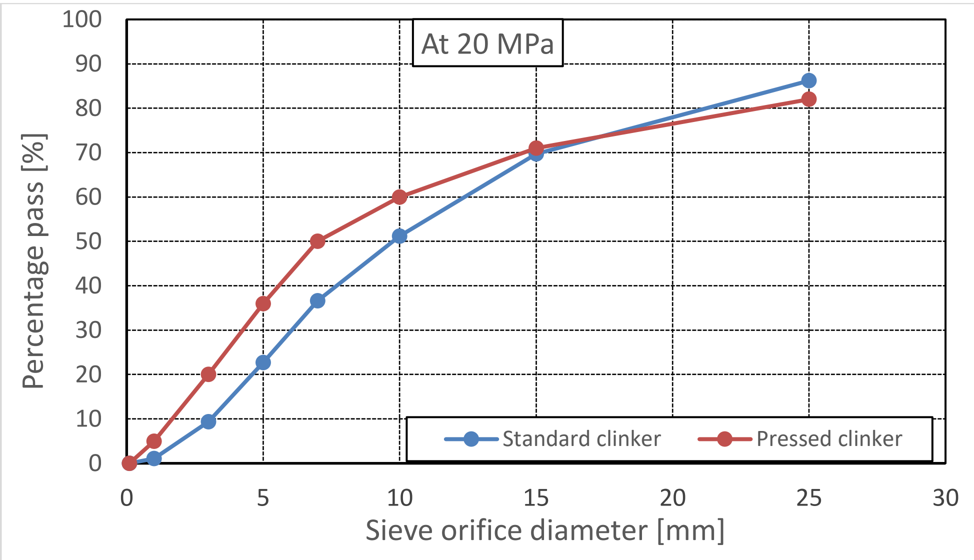

Fig.3. Particle size distribution of standard clinker compared to pressed clinker (20 MPa)

- sample (batch) 10 - clinker pressed at a pressure of 100 MPa whose particle size distribution after pressing is presented in fig.4.

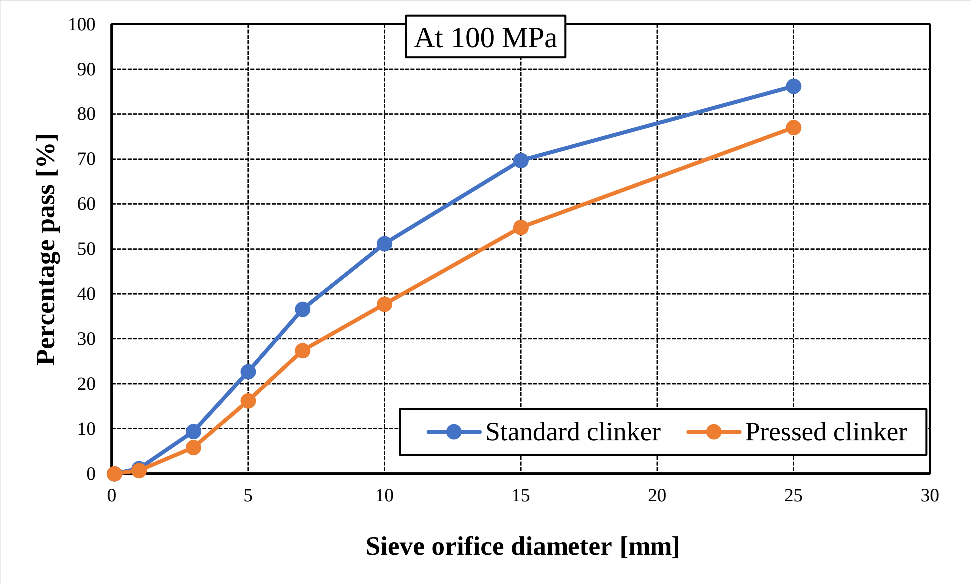

Fig.4. Particle size distribution of standard clinker compared to pressed clinker (100 MPa)

- sample (batch) 11 - clinker pressed twice at a pressure of 100 MPa whose particle size distribution after pressing is shown in fig.5.

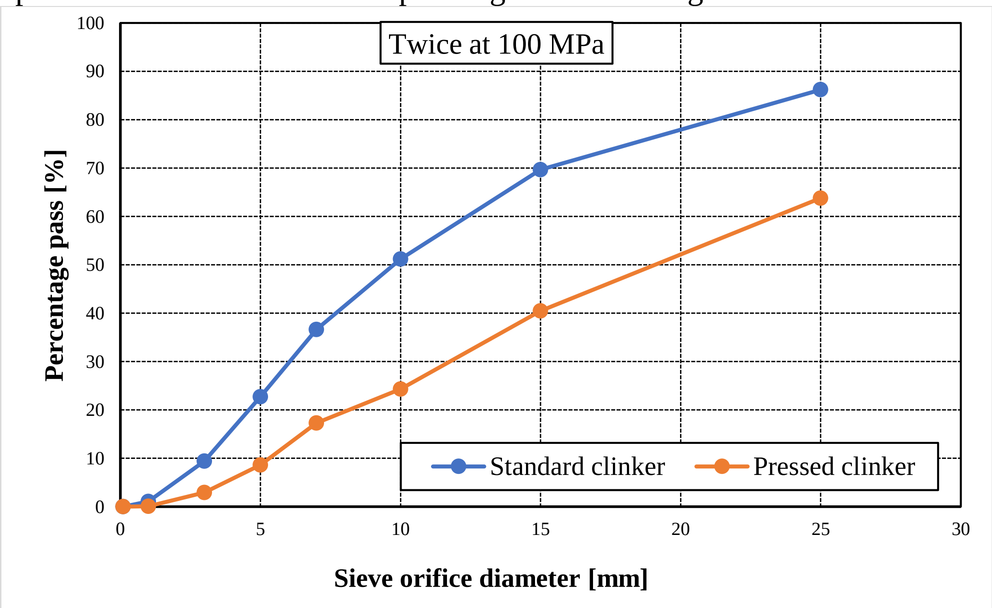

Fig.5. Particle size distribution of standard clinker compared to twice pressed clinker (100 MPa)

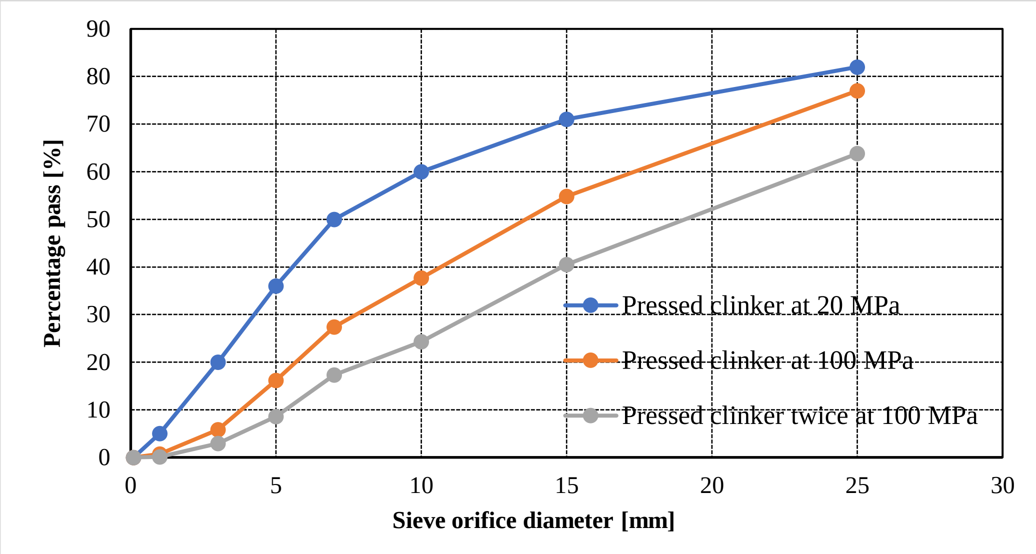

Fig.6. Comparation between different types of analyzed pressed clinker

The evolution for three types of pressed clinker is presented in figure 6, where it can be noticed that the evolution decreases with pressure increase.

In order to establish the electricity consumption, compared between the standard clinker and the pressed clinker, determinations of the grinding ability were made on the 11 clinker loads at different specific surfaces, respectively: 2500 cm^2/g, 3000 cm^2 / g, 3500 cm^2/g and 4000 cm^2/g. For the 11 clinker loads (samples) the grinding ability was determined as follows: in samples 1 and 2 up to a fineness of 2500 cm^2/g; in samples 3 and 4 up to a fineness of 3000 cm^2/g; at samples 5 and 6 up to a fineness of 3500 cm^2/g; at samples 7 and 11 up to a fineness of 4000 cm^2/g.

The analysis of the data shows an insignificant influence of the pressing at the value of 20 MPa according to the grinding ability of the clinker highlighted by the consumption of electricity, namely:

- the specific electricity consumption in the laboratory, at a fineness of 2500 cm^2/g Blaine was at the standard clinker of 33.759 kWh/t compared to 32.883 kWh/t at the clinker pressed at 20 MPa; the granulometric curves were drawn both for the standard clinker and for the two types of clinker pressed once, respectively twice; the results are presented in tables 3-5 and in fig.7-9; the material introduced for sample no. 9 weighed 20.868 kg (clinker: 95%; gypsum: 5%; mass: 1739 g/l).

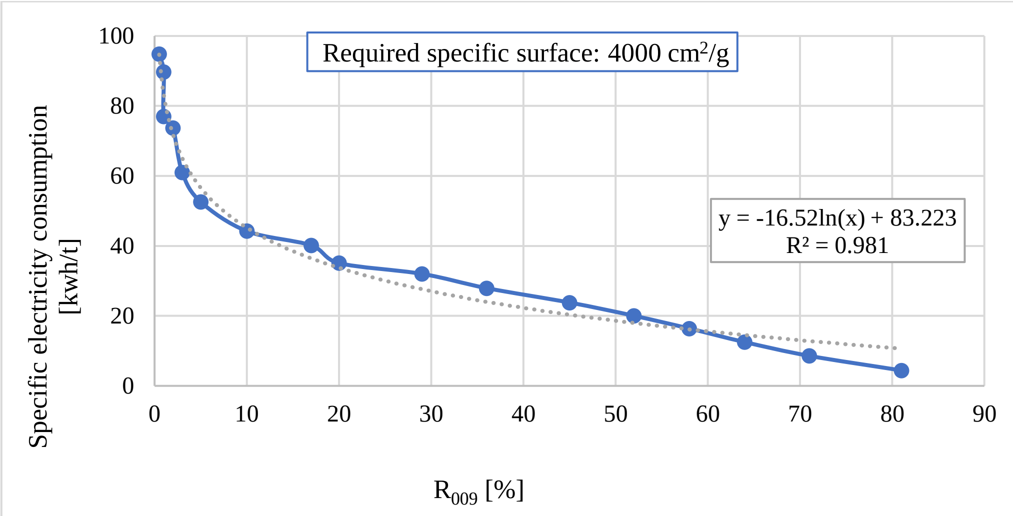

Fig .7. Ability to grind in the CEPROCIM type laboratory mill of the standard clinker (specific surface required - 4000 cm^2/g)

Table 3

Ability to grind the standard clinker in the laboratory mill

Grinding time, min		Electricity consumption, kWh		Cumulative specific consumption, kWh/t	Fineness	
partial	cumulative	partial	cumulative		Residue, %	Specific surface, cm^2/g
5	5	0.092	0.092	4.41	81.0	-
5	10	0.087	0.179	8.58	71.0	-
5	15	0.082	0.261	12.51	64.0	-
5	20	0.081	0.342	16.39	58.0	-
5	25	0.076	0.418	20.03	52.0	-
5	30	0.079	0.497	23.82	45.0	-
5	35	0.086	0.583	27.94	36.0	1780
5	40	0.085	0.668	32.01	29.0	1990
5	45	0.083	0.751	35.09	20.0	2230
5	50	0.087	0.838	40.15	17.0	2310
5	55	0.085	0.923	44.23	10.0	2470
10	65	0.175	1.098	52.61	5.0	2800
10	75	0.175	1.273	61.00	3.0	3000
15	90	0.265	1.538	73.70	2.0	3410
4	94	0.069	1.607	77.00	1.0	3510
15	109	0.226	1.873	89.75	1.0	3857
6	115	0.106	1.979	94.83	0.5	4000

Note: The material introduced in the mill for sample no. 10 was: 21.384 kg (clinker: 95%; gypsum: 5%; literal mass: 1782 g/l).

Tabel 4

Ability to grind the pressed clinker in the laboratory mill

Grinding time, min		Electricity consumption, kWh		Cumulative specific consumption, kWh/t	Fineness	
partial	cumulative	partial	cumulative		Residue, %	Specific surface, cm^2/g
5	5	0.111	0.111	5.19	72.0	-
10	15	0.165	0.276	12.90	58.0	-
10	25	0.164	0.440	20.57	42.0	-
10	35	0.177	0.617	28.85	30.0	-
10	45	0.178	0.795	36.71	14.0	
5	50	0.083	0.878	41.06	11.0	
1	51	0.017	0.895	41.85	10.0	2360
2	53	0.033	0.928	43.40	8.0	2400
3	56	0.051	0.979	45.78	6.0	2530
15	71	0.264	1.243	58.12	3.0	2900
3	74	0.055	1.298	60.7	2.0	2930
3	77	0.056	1.354	63.31	2.0	2970
15	92	0.264	1.616	67.62	1.0	3402
2	94	0.033	1.651	70.61	0.5	3519
12	106	0.209	1.860	86.98	0.5	3950

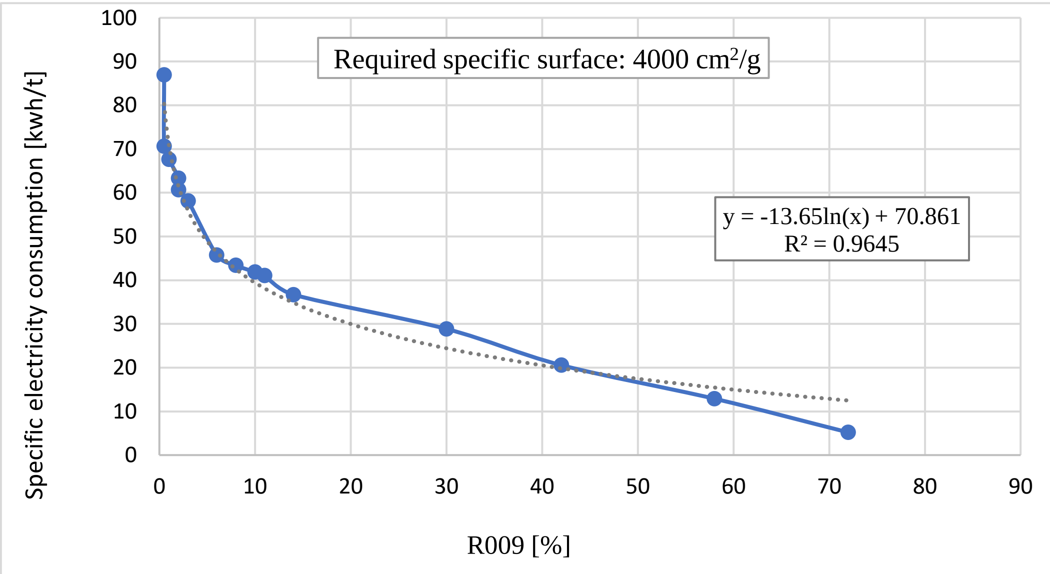

Fig.8. Ability to grind in the laboratory mill type CEPROCIM SA of the clinker pressed once 100 MPa (specific surface required - 4000 cm^2/g)

Table 5

Ability to grind the clinker press twice in the laboratory

Grinding time, min		Electricity consumption, kWh		Cumulative specific electricity consumption, kWh/t	Fineness	
partial	cumulative	partial	cumulative		Residue, R_{009}%	Specific surface, cm^2/g
5	5	0.087	0.087	3.947	60.0	-
5	10	0.084	0.171	7.757	57.0	-
5	15	0.079	0.250	11.341	51.0	-
5	20	0.079	0.329	14.920	46.0	-
5	25	0.081	0.410	18.60	41.0	-
10	35	0.172	0.582	26.40	24.0	2058
5	40	0.089	0.671	30.44	16.0	2258
4	44	0.070	0.741	33.61	12.0	2442
2	46	0.034	0.775	35.16	10.0	2512
15	61	0.256	1.031	46.77	4.0	3027
15	76	0.262	1.293	58.66	2.0	3370
5	81	0.089	1.382	62.70	1.0	3516
15	96	0.264	1.646	74.67	1.0	3833
5	101	0.0091	1.737	78.79	0.5	3950

The grinding ability was performed on the standard clinker, the clinker pressed once and the clinker pressed twice, up to a fineness of 4000 cm^2/g Blaine. The analysis of the data shows a more pronounced fractionation of the clinker in the case of pressing twice compared to the one pressed once (fig.8).

The data obtained expressed in industrial consumption show that for grinding the industrial standard clinker would consume 32.6 kWh/t compared to 31.0 kWh/t for the clinker pressed once and 27.7 kWh/t for the clinker pressed twice.

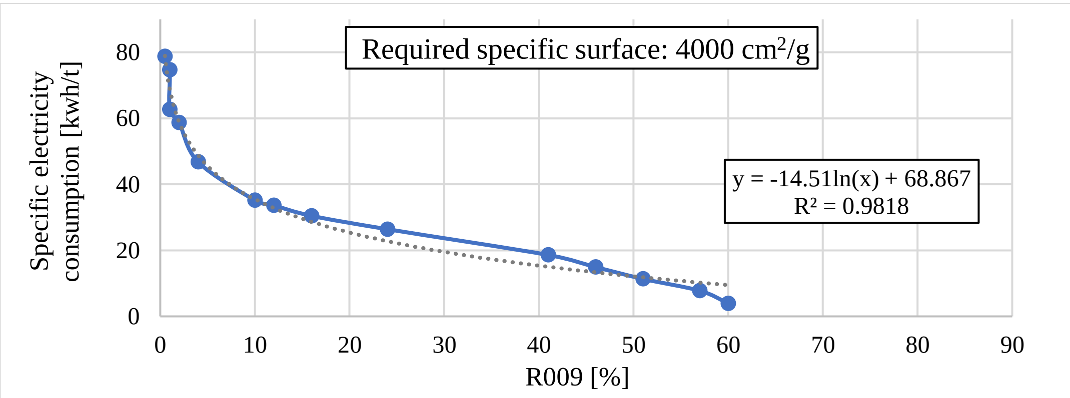

Fig.9. Ability to grind in the laboratory mill type CEPROCIM SA of the clinker pressed twice at 100 MPa (Specific imposed surface -4000 cm^2/g)

In the case of the once pressed clinker the electricity consumption is lower by 5%, and in the case of the twice pressed clinker is by 15%. The analysis of the above data shows that the use of prestressing materials by pressing becomes cost effective at pressures higher than 200 MPa.

4. Conclusions

The laboratory works within CEPROCIM have highlighted the efficiency of pressing the clinker before grinding by reducing the electricity consumption at pressures higher than 100 MPa.

It is necessary to build a medium-capacity installation that can be installed within an existing grinding line and thus determine the operating parameters and efficiency in terms of electricity savings and increased hourly productivity.

The purpose of this paper is the comparative study of grinding two cement clinkers. Grinding tests were also performed for ten samples to determine the parameters that influence the grinding ability of its clinker. The results of the grinding energies calculation according to the law elaborated by Von Rittinger and the study of the microstructure of the two clinkers show good agreements. The analysis and the obtained results allowed us to interpret the granulometry and the clinker microstructure to control the quality and the resistance.

We can conclude that the variations between the two clinkers, especially at the crushing level, are due to several characteristics such as granulometry, chemical composition, minor elements (alkaline, free lime), and combustion conditions. So the whole matrix is responsible for the differences encountered at the time of the study for these two types of clinker.

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