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The charachterization and the utilization of cement kiln dust (CKD) as partial replacement of portland cement in mortar and concrete production

Cement Kiln Dust (CKD) is a by product material of cement manufacturing industry.The physical and chemical characteristics of CKD depend on raw materials, type of kiln operation, dust collection systems and fuel type used in cement clinker production. Free lime is found in CKD.

Depending on the concentration of lime (CaO) and the cementing minerals, CKD may have any cementitious value.

The majority of CKD is recycled by returning it back into the cement kiln as raw material. Recently, has been a trend of utilizing CKD in soil stabilization, sewage treatment, etc. In this study attempts are made at utilizing it as partial replacement of Portland cement in mortar and concrete production. The CKD and Portland cement are characterized from a chemical, mineralogical and physical point of view. Several blends of binding materials are prepared using 0-45% CKD as partial replacement of Portland cement. In addition to CKD, in some other blends, fly ash and blast furnace slag are added, too. The prepared mixtures are then studied in terms of their properties both in fresh and hardened state. Tests are carried out on the mortars cured at different time lengths; their flexure and compressive strength, durability and porosimetry are determined.

***Key words**: CKD, Portland cement, charachterization, utilization*

INTRODUCTION

The production of 1 ton cement requires about 2.8 ton raw materials (including fuels and other materials). 5 to 10% of these materials are dust out of the dryers, mills, kilns, coolers and transportation facilities. Cement Kiln Dust (CKD) is denominated the solid, highly alkaline material removed with the cement kiln exhaust gas and collected at bag house filters and/or electrostatic precipitators. With modern manufacturing techniques, it is technically possible to return most of the CKD back into the clinker making process. So, the majority of CKD is recycled back into the cement kiln as raw feed. Recycling this by-product back into the kiln not only reduces the amount of CKD to be managed outside the kiln; but it also reduces the need for limestone and other raw materials, that saves natural resources and helps to conserve energy. But, the recycle of cement kiln dust back into the kiln, is not done always due to the high alkali content in CKD. Most international specifications restrict the alkali content of cement to less than 0.6% to avoid alkali – silica reaction.

Profitable uses of Cement Kiln Dust removed from the cement manufacturing process include the following:

- Agriculture: potash/lime source and animal feed;
- Civil engineering: fill, soil stabilization and fly ash stabilization;
- Building materials: lightweight aggregates, blocks, low-strength concrete and masonry cement;
- Sewage and water treatment: coagulation aid and sludge stabilization;
- Pollution control: sulfur absorbent, waste treatment and solidification, etc.

There are studies that have shown that CKD can be used alone as partial replacement of Portland cement, but often it is more effective when it is used in combination with other cementitious materials, including fly ash and slag.

The use of CKD as an addition to Portland cement has been evaluated by a number of researches. Some examples on the use of CKD blended with Portland cement as well as fly ash and ground granulated blast furnace slag are published by Detweiller et al. The researchers have found that cements containing only CKD have reduced workability, setting times and strength. The loss of strength is attributed to alkalis in the dust. It is believed that the use of fly ash with CKD dilutes the alkalis and thus improves the strength. Fly ash is mainly composed of vitrified (amorphous) alumina-silicate melt in addition to a small amount of crystalline minerals, such as quartz, mullite, mica, etc. Due to the high degree of poly-

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merization at which tetrahedral silicate is bridged with oxygen, most fly ashes, especially Class F fly ash, react very slowly with water and lime at room temperature. Some researches have indicated that if the three materials (Portland cement, CKD and fly ash) are appropriately blended, the alkalis from CKD my activate hydration of fly ash and the blends may create a material with high cementitious characterristics [1]. The addition of slag to cement-CKD blends generally decreases the workability, but it increases the strength compared with blends containing no slag.

Ravindrarajah reported that kiln dust could be used in masonry and concrete blocks without loss of strength or workability [2-4]. His study showed that up to 15% of the Portland cement could be replaced with CKD. If higher percentages of dusts are used, the setting time is retarded, workability is reduced and water demand is increased.

Daugherty and Funnel reported that the use of up to ten percent interground CKD did not have any adverse affects on the setting time, soundness or shrinkage of the final Portland cement concrete. However, the strength results varied, most likely attributed to the different dust composition [5].

EXPERIMENTAL

The objective of this study is the characterization of Cement Kiln Dust (CKD) and of the cementing blends formed by the partial replacement of Portland cement with CKD, fly ash, and blast furnace slag; the evaluation of the CKD influence on chemical and physico-mechanical properties of cementing blends as well as on the characteristics of fresh and hardened mortars produced with them.

Portland cement CEM I, type 42.5 N (clinker + 5% gypsum) produced in Fushe-Kruja Cement Factory, Albania, is used for the tests. For the partial replacement of Portland cement is used CKD, fly ash and blast furnace slag.

CKD is taken from the cyclone of the exhausted kiln gases. In Fushe-Kruja Cement Factory, are produced 5% (around 50,000 ton) CKD per year. Actually all the kiln dust produced is returned back in the process.

The fly ash and the blast furnace slag are taken from Macedonia. Standard sand, conform ISO 679:1989, is used for the mortar production.

X-ray fluorescence (XRF) is used to determine the major elements likely to be present in CKD and Portland cement. The chlorine and alkaline content of CKD and PC, as well as the chemical content of fly ash and slag, are determined by analytical chemical techniques.

The mineralogical characterization of CKD and Portland cement includes X-ray diffraction (XRD). The XRD is performed with a Brucker D8 Difractometer on pressed powder samples. Scanning is performed in the range of $3^o \leq 2\theta \leq 75^o$ with a scan rate of 0.02 $^o\,2\theta$ per second.

Seven mortars containing Portland cement, cement kiln dust, fly ash and blast furnace slag as a binder have been investigated. The water-binder ratio varied between 0.5 and 0.6 [6].

Table 1 - Different mix designs of cementing materials

Recipe Ingredients	*(in %)*						
	CEM I	15 CKD	30 CKD	45 CKD	SFA 0.5	SFA 0.6	***SLAG***
CEM I	100	85	70	65	70	70	***70***
CKD	-	15	30	45	15	15	***15***
Fly ash	-	-	-	-	15	15	**-**
Slag	-	-	-	-	-	-	***15***
w/b ratio	***0.5***	***0.5***	***0.5***	***0.5***	***0.5***	***0.6***	***0.5***

For all cementing binders and CKD, the physical properties (density, bulk volume, the Blaine specific surface, fineness) are determined.

The fineness of CEM I and CKD is determined with sieve analyses (dry method).

Normal consistency is a term that is used to describe the degree of plasticity of a freshly mixed paste.

The normal consistency (w/b ratio expressed as a percentage) and setting times are determined according EN 196-3, for all fresh binders using a Vicat apparatus.

The setting times (initial and final) are used to evaluate if a paste is undergoing normal hydration reactions.

Figure 1 - XRF apparatus

Figure 2 - Fineness apparatus

Figure 3 - Vicat apparatus used for normal consistency and setting time determination

Flow is used to describe the ability to flow (mobility) of mortars. The flow for each fresh binder blend is determined on a flow table as described in EN 196-3.

Figure 4 - The flow table used for the flow measurements

Soundness refers to the ability of a paste to retain its volume after it has set. Unsoundness can arise from excessive amounts of hard burned free lime or free magnesia and has the potential to cause delayed destructive expansion. For each binder blend paste the same w/b ratio (used to attain normal consistency and initial setting time) is used for autoclave tests with Le Chatelier rings.

Figure 5 - Le Chatelier rings used for the autoclave tests

Mechanical strength is the most commonly used method to assess binder quality. The flexure and compression strength for each binder is determined according EN 196-1 at 2, 7, 28, 90 and 270 days. 4 x 4 x 16 cm mortar prism specimens are prepared by mixing one part of binder blend material, 2.75 parts of standard sand and distilled water addition.

The mechanical strength results are the averages of three test specimens from a single batch at the specified curing time.

Resistances to sulfate attack, as well as resistance to freezing and thawing are determined at the hardened specimens that are cured for three months in severe conditions, respectively in 5% Na_2SO_4 solution and at ± 15^oC in four hour cycles.

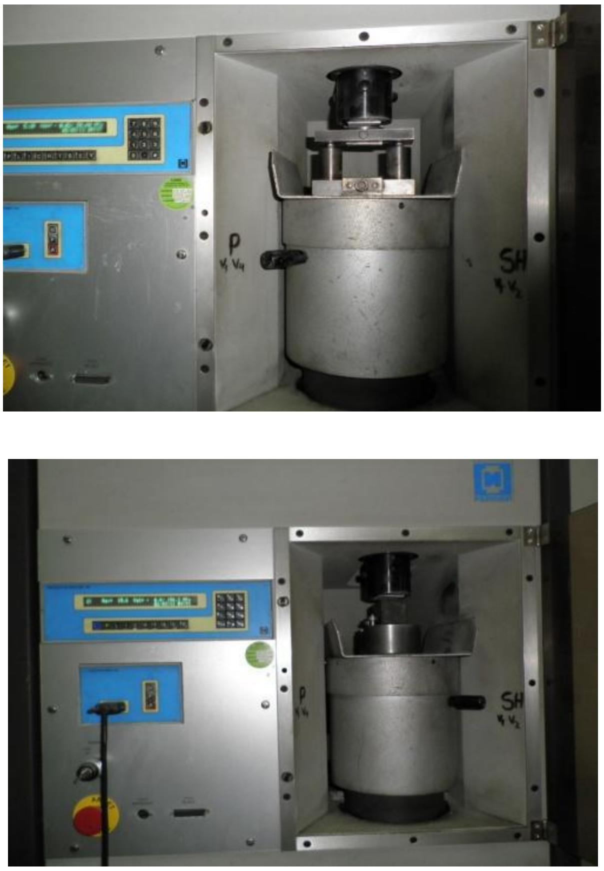

Figure 6 - The apparatus used for flexure and compressive strength measurements

By the use of mercury intrusion porosimetry, MPI, the pore size distribution of the hardened mortars at 270 days is defined. Type Pascal 440 MPI is used for porosity measurement.

Figure 7 - The prisms cured for sulfate resistance measurements

Figure 8 - Mercury intrusion porosimeter used for porosity measurement

Knowledge of the distribution of pore sizes is a useful element in the microstructural characterization of hardened mortars. The range of equivalent pore diameter explored cover five orders of magnitude, from several thousand nanometers down to approximately 1 nanometer. The basis of the mercury intrusion method is based on the simple physical principle that a non wetting fluid, i.e. one whose contact angle is greater than 90^o for a particular solid, will not spontaneously intrude the pores of that solid but will do so if sufficient pressure is applied. The pressure required depends on the contact angle, the pore diameter and the surface tension of the liquid according to Washburn equation:

$$\Delta P = \frac{2\gamma \cos\theta}{r_{pore}}$$

θ = contact angle between the solid and mercury

γ = surface tension of mercury

From the Figure 9, it is obvious that the mercury intrusion can not be used to analyze closed pores, since the mercury has no way of entering that pore [7].

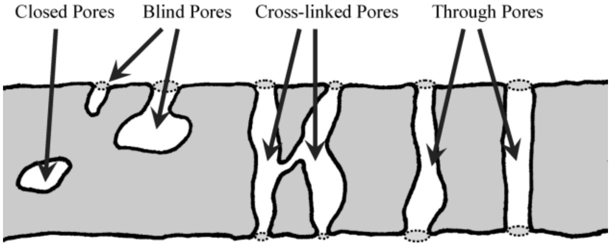

Figure 9 - Schematic representation of pores

RESULTS AND DISCUSSION

The Portland cement, CKD, fly ash and slag compositions are presented in the Table 2.

Table 2 - Chemical composition of ingredients used in mortars production

	(in %)											
	XRF analyses						Flame photometry			CaO_f	Cl^-	*LOI*
	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	K_2O	Na_2O_{eq}			
CEM I	61.61	21.30	5.45	3.22	1.87	3.01	1.87	0.57	2.45	1.45	0.015	*1.47*
CKD	41.90	13.16	3.51	2.59	1.08	1.13	2.10	0.70	2.56	29.40	0.049	*35.50*
Fly ash	5.07	47.62	23.76	10.94	7.69	0.91	-	-	-	-	-	*1.85*
Slag	*20.73*	*44.7*	*8.83*	*2.17*	*16.48*	*0.34*	-	-	-	-	-	-

Prior to XRF analysis, the loss on ignition is performed by igniting the sample (dried to a constant mass at 110°C) in a muffle furnace at 950 ± 50°C in an uncovered crucible for 1 hour. For CEM I, the LOI value obtained results from either exposure to moisture or CO_2. Since we used Portland cement and it consists only of clinker and gypsum, there is no contribution of CO_2 from carbonate addition. Whereas, for CKD, the LOI value not only reflects dehydration and decarbonization, but also the presence of volatiles (alkali, sulfate and/or chloride). A large percentage of the CKD volatiles will be released from the sample into the atmosfere during the LOI test and during preparation of the fused beads since they are less stable in CKD than in PC at 950 ± 50°C. So there are two problems: (i) the LOI is not just CO_2 but even volatile alkali, sulfate and/or chloride and (ii) the XRF quantification of alkali, sulfate and/or chloride is underestimated compared with the results taken respectively with flame photometry and analytical chemical techniques.

The free lime test for PC is typically used to determine the free calcium oxide content. This test, however, is also sensitive to calcium hydroxide. The free lime test gives the total of free calcium oxide plus calcium hydroxide content and it does not differentiate each of them. This is not an issue for PC free lime analyses since the presence of calcium hydroxide is rare in it. However, the CKD used in our experiments is exposed to moisture during processing to reduce fugitive dust. Therefore, the results from the free lime test for CKD should be considered as representative of combined free calcium oxide and calcium hydroxide contents.

From Table 2 we notice that the total of free oxide and hydroxide of calcium, as well as LOI are much higher in CKD, than in Portland cement.

Silica and the oxide of calcium are the main constituents of Portland cement and CKD although these oxide contents are lower in CKD than in Portland cements.

On the other hand the alkalis are higher in CKD than in PC. This is not surprising, since volatile alkalis leave the kiln with CKD.

Chlorides, also, are three times higher in CKD than in PC [6].

The CKD and PC mineralogical analysis (identification of the different phases) is used as an essential complement of the chemical analysis. The influence of CKD in a CKD-PC blend may vary depending on the form in which the diferent elements actually exist within the CKD and how they might be expected to react during hydration. The X-Ray patterns for CP and CKD are presented in the Figures 10 and 11.

From the XRD patterns presented above we notice that calcium silicates, calcite, calcium magnesium aluminum silicates, gypsum, etc are the main mineralogical constituents of Portland cement. Whereas for the Cement Kiln Dust the main constituents are quartz, calcite, illite, etc.

Many authors indicate that CKD can consist of up to 50 % calcium carbonate, up to 30% quartz and clays and dehydrated clays. It, also, can contain any or all of the four major clinker phases.

Due to the absence of calcium silicates in the CKD used at our experiments, it is expected that this CKD has not self cementitious value and the CKD strength gain contribution in the CKD-PC blends will be low.

The effects of the limestone of the CKD, when the CKD is used as a partial substitute of PC, can be both physical and chemical [8].

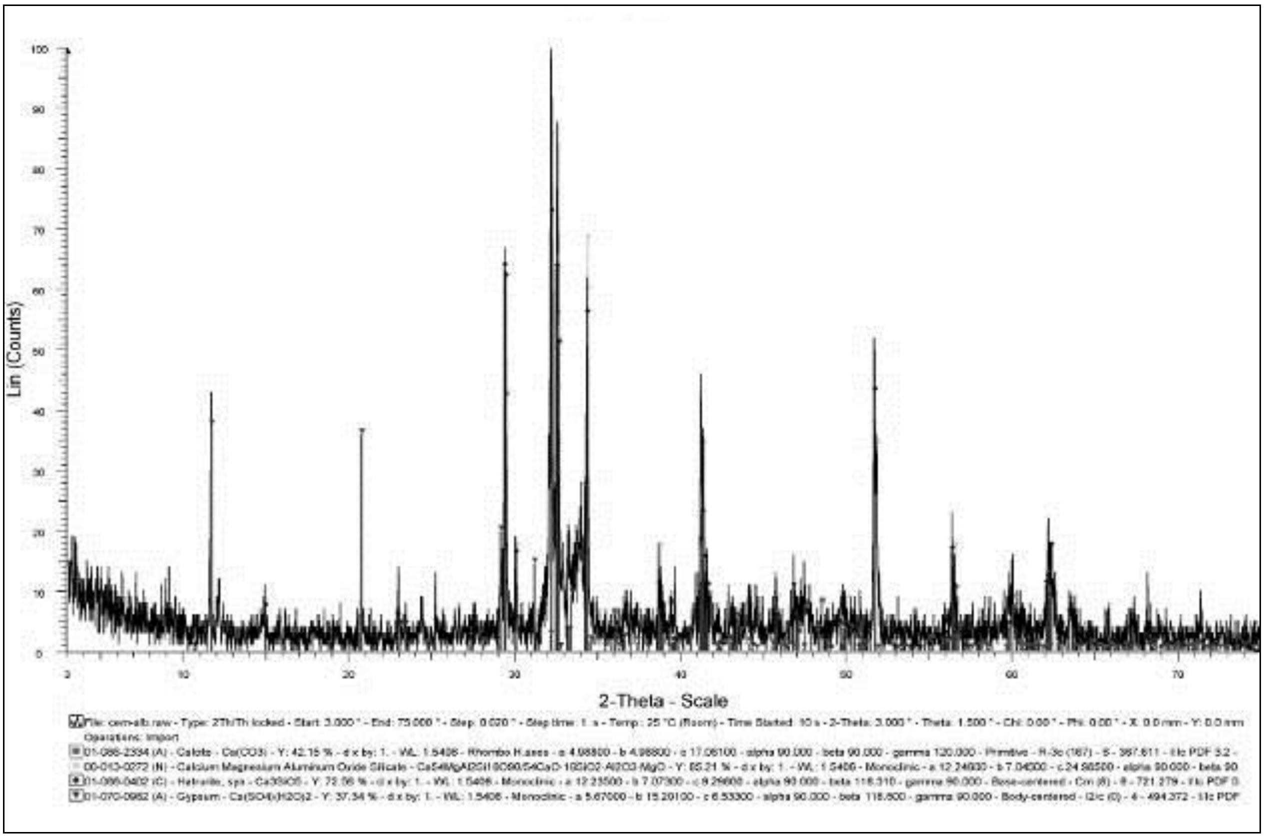

Figure 10 - X-Ray pattern of Portland cement PC

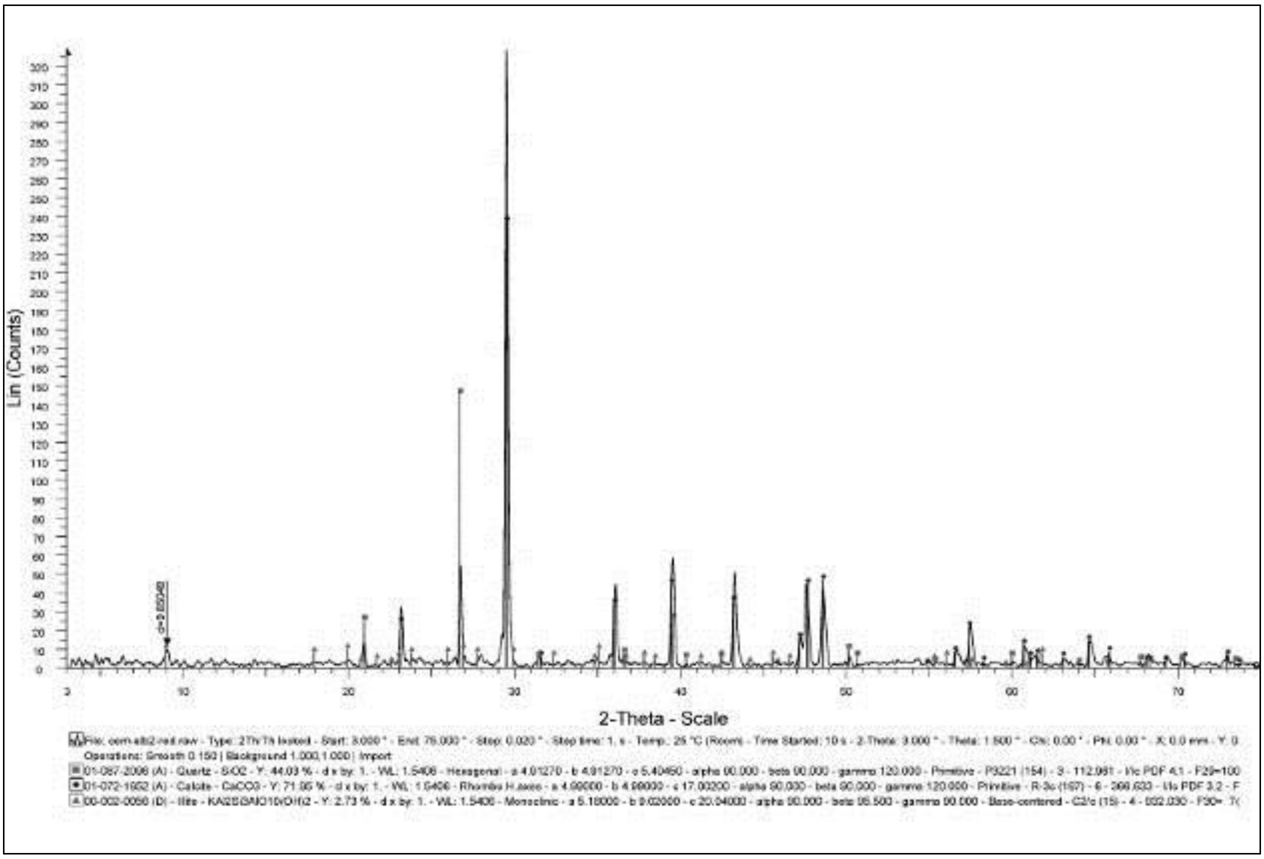

Figure 11 - X-Ray pattern of cement kiln dust CKD

Calcium carbonate influences the hydration of C_3S. Limestone accelerates and enhances the rate of formation of C-S-H and CH. Probably it offers nucleation sites for growth [9]. Calcium carbonate, also, can form a complex, calcium carbosilicate hydrate, with the hydrated products of C_3S. During normal PC hydration, C_3A and calcium sulfate react to form AFt (Aluminate-Ferrite-Trisubstituted or Ettringite). Sulfate depletion typically occurs before the C_3A consumption is complete, resulting in the conversion of AFt to AFm (Aluminate-Ferrite-Monosubstituted, Monosulfoaluminate, or Monosulfate). The presence of calcium carbonate, however, alters these reactions. First, AFt formation is accelerated in the presence of calcium carbonate [10]. Second, the conversion of AFt to AFm is delayed or prevented due to the reaction between C_3A and calcium carbonate to form calciumcarboaluminate. The formation of calciumcarboaluminate occurs as some of the sulfates are replaced by carbonate ions during C_3A hydration. So, the limestone or CKD can be used for partial substitution of the gypsum to control the early hydration of C_3A. Calcium carbonate effects, too, on the heat evolution during hydration of limestone filler cements. As the amount of limestone increase, the both, major heat peak and the total amount of heat released, decrease. The water demand is reduced with limestone filler cements and this is attributed to the improved particle packing. Literature shows that up to 5% limestone addition can provide strengths similar to PC without limestone. Beyond the 5-10 % range of limestone addition to PC, strengths are lower than PC alone, due to dilution effect.

The quartz (contained in CKD) is inert. The partial replacement of PC with CKD may have an impact on cement properties due to the presence of unreactive raw materials within CKD. Quartz has physical effects on CKD-PC blends due to nucleation and filler effects.

Illite is a clay mineral. The presence of clay can lead to an increase in water demand. The effect of clay on hardened mortars can be deleterious to freezing and thawing resistance. Clay minerals could cause problems in hardened mortar if they swell when exposed in water. No hydration products are generated by clays in the presence of PC.

The fineness of PC and CKD is presented in Table 3 and Figure 12.

From table 3 we notice that CP is mainly (90.73%) composed of particles below 38 µ**.** Whereas in the CKD this fraction is lower (78.7%). The fraction above 200 µ**,** is lower (0.01%) in PC than in CKD (0.5%). So, the CKD used in our experiments is coarser compared to PC. This is expected since after burning in the kiln, the clinker is ground to Portland cement where its fineness is controlled; whereas the CKD is taken as kiln by-product from the cyclone of the exhausted kiln gases, (where the product is cement clinker, in the form of granules around 30 mm). These results are in accordance with the data given in the literature for CKD of precalciner process.

Table 3 - Fineness of PC and CKD (dry method)

Particle size (μ)	Amount (in %)	
	Portland cement	Cement kiln dust
Above 200	0.01	0.5
90÷200	0.19	2.1
75÷90	0.20	1.9
63÷75	0.40	4.7
53÷63	2.26	2.1
45÷53	3.14	6.2
38÷45	3.07	3.8
Below 38	90.73	78.7

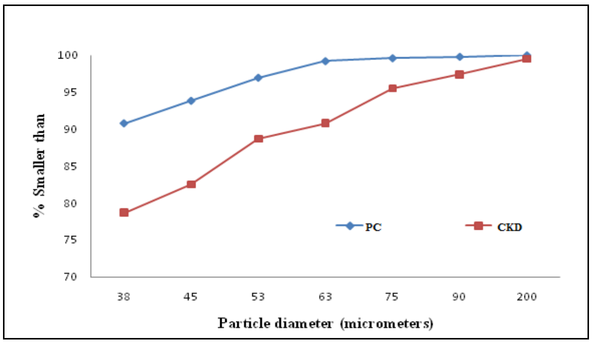

Figure 12 - The particle size distribution of CP and CKD

It is known that the cement particles of size 3-30 µ (the amount of which is recommended to be above 65%) have the major influence in cement mechanical strength.

From the Figure 12, it is seen that the mean particle size or D_{50} (the equivalent diameter where 50% of the particles have a smaller diameter) for both PC and CKD is below 38 µ. With sieve analysis it was not possible to determinate the particle size distribution below 38 µ.

With the data taken from the sieve analysis (given in Table 3), it was not possible to complete the graph of the whole particle size distribution.

This would be possible by using the data taken from the particle size laser diffractometry analyses. In the figure 12 are presented the particle size distributions of some different CKDs and of a Type I PC for comparison. In these graphs CKD-1 (long-dry process) and CKD-2 (precalciner process) have the finest and coarsest particle size distributions respecttively. CKD-3 (preheater/precalciner process) and CKD-4 (wet process) have particle size distributions very similar to that of the Type I PC.

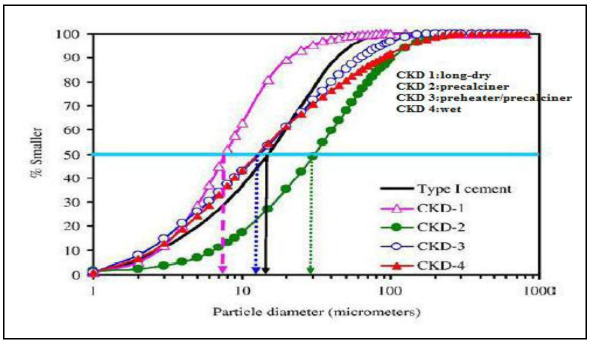

Figure 13 - CKDs and PC particle size distribution [9]

In the Table 4 are presented some other physical characteristics of PC and CKD studied in our experiments, as well as of the cementing binders 15 CKD, 30 CKD, 45 CKD, SFA and SLAG prepared in our experiments, too.

Table 4 Some physical characteristics of materials used

Cementing binders	Bulk volume (gr/l)	Density (gr/cm$^{3)}$	Specific surface (cm^2/gr)
CEM	1025	3.21	3705
CKD	742	2.42	-
15 CKD	982.5	3.18	-
30 CKD	940	2.8	-
45 CKD	918	2.8	-
SFA	899	2.72	-
SLAG	-	2.99	-

The density of CKD is lower than the PC density. Consequently, when CKD is used as partial replacement of PC by mass, more CKD particles are required to replace the PC, which will affect rheological properties of PC-CKD blends. In general, the same trend is for the bulk volumes of cementing binders, too.

In the Figures 14 and 15 are presented the workability (the water required to maintain normal consistency) and the setting times of the fresh mortars produced with the mix designs shown at the Table 1.

The purpose of the normal consistency test is to assess how CKD influences in the water demand of the CKD-blend pastes. From the Figure 14, is seen that at 15%, 30% and 45% replacements of PC, all the PC-CKD blends require more water to maintain a normal consistency penetration than the respective PC alone. The water demand is increased with the increase of the CKD amount used in blend. The literature suggests that the increased water demand may be attributed to the high amount of alkalis, sulfate, volatile salts, and free lime in CKD compared with PC. On the other hand, the coarseness and particle size irregularity, as well as the increased solid volume of CKD (since the density of CKD is lower than that of the cement) increase the viscosity of the blended fresh pastes, thus their water demand [11-12].

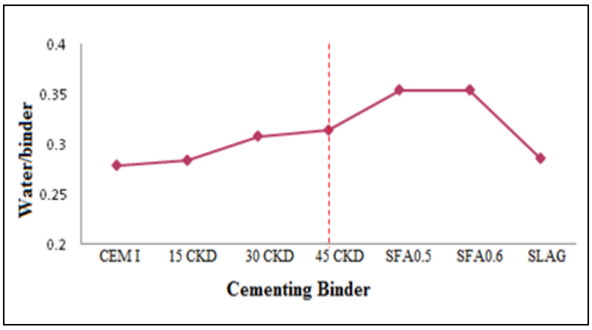

Figure 14 - Water/binder ratio for normal consistency of fresh pastes

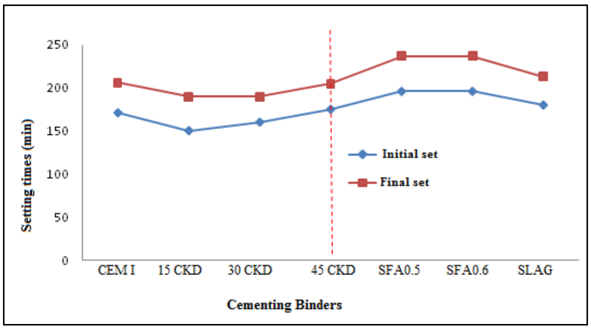

Figure 15 - Setting times for all cementing binders

The water demand increase is higher when, in addition of 15% CKD, another 15% fly ash is added as replacement of PC. But, for the mix design of 15% CKD and 15 % slag at the SLAG fresh mortar, the water demand is comparable with the PC paste without any additive.

The initial setting time of PC is important as, in addition to workability, it provides an indication of how long the mixture will remain in plastic condition. It is desirable for concrete to harden and develop strength within a reasonable time after it has been placed. For these reasons, the impact of CKD as a partial replacement of PC on the initial setting time is very important.

The plain cement paste has an initial setting time of 171 minutes and the final setting time of 206 minutes. As the CKD replacement increases, the setting time decreases. The increase of water demand and the decrease of the setting times with the increase of CKD are contrary to what one could expect, since it is well known that an increase in water/cement results in longer setting times for a given paste. But the established influence of w/c refers to its effect on a single blend and not on blends with different chemical/mineralogical and physical properties (CP-CKD or CP-CKD-pozzolana blends). The lower setting times values in PC-CKD pastes compared with PC pastes is considered to be affected from the high amount of lime and alkalis in CKD which accelerate hydration and lead to fast setting. When the fly ash is used the increase of setting times is normal. The setting times of SLAG fresh paste are comparable with the setting times of plain cement paste.

The flow of the fresh pastes is presented at the Figure 16.

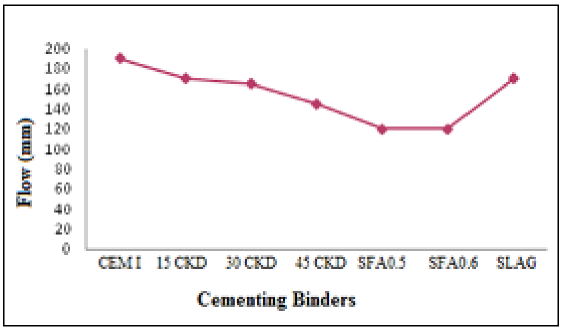

Figure 16 The flow of fresh pastes of different cementing binders

The flow of the fresh paste is decreased with the increase of CKD addition. In general, will the filler addition in cement paste, the paste flow is increased. The CKD role in the flow decrease cames from the presence of free lime in CKD, which easily forms precipitate of the calcium hydroxide. So, the CKD behavior is different from that of the fillers. This means that the CKD is not completely inert. The SLAG paste with PFC-slag addition has almost the same flow as the 15 CKD paste. So the slag addition does not affect at paste flow with low content of CKD.

Neither the PC paste nor the blend pastes showed any expansion using Le Chatelier apparatus at the autoclave test.

The flexure and the compressive strength development of hardened mortars of different mix design after 2, 7, 28, 90 and 270 days of curing, tested according EN 196-1 are shown in Figures 17 and 18.

From the figures 17 and 18 it is seen that the strength development of cementitious blends is influenced by the CKD presence. The increase of the amount of CKD addition (0-45%) results in the decrease of the flexural and compressive strengths at all ages. This is due to the mineralogical and fineness properties of CKD used at our experiments. This CKD is characterized as a material with very low cementing properties (without cementing minerals and being coarser compared with Portland cement).

As CKD content increases (0-45%) the aggregate-paste bond is weaker, so the CKD weakens the hardened cement paste. The high alkalis and free lime content present in CKD may modify the hydration products, weakening hardened matrix.

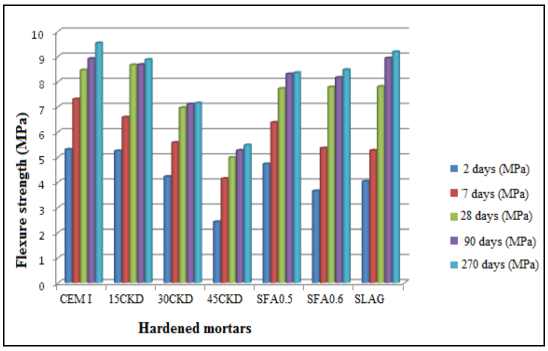

Figure 17 - Flexure strength for hardened mortars of different mix designs

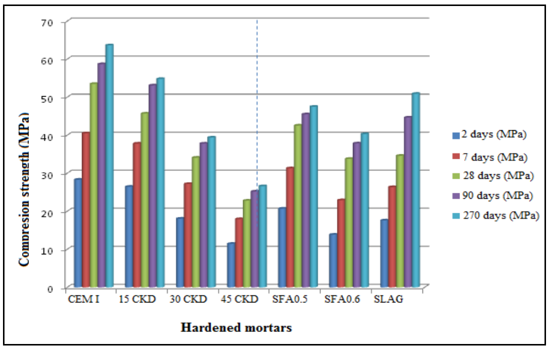

Figure 18 - Compression strength for hardened mortars of different mix designs

With the fly ash and slag addition in the PC-15%CKD blend, the mechanical strengths are farther decreased at all ages compared with hardened PC pastes. The mechanical strength reduction is due to the cement content reduction.

But, in general, the rate of strength gain increases with aging of the hardened CP-45CKD and CP-CKD-fly ash and CP-CKD-slag mortars at 7, 28, 90 and 270 days compared with the early strengths gain values at 2 days. In the Figures 19 and 20 are shown the results of each represented blend.

Figure 19 - Flexure strength increase at later ages compared with that at the 2nd day

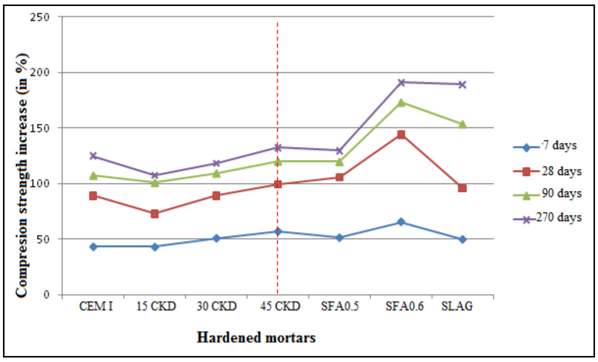

Figure 20 - Compression strength increase at later ages compared with that at the 2nd day

The CKD addition as partial substitute of PC decreases the durability of the hardened mortar at freezing and thawing. In the Figure 21 are shown the decreases (in %) of the compression strengths after 25 cycles of freezing and thawing of the hardened samples with different amounts of CKD as well as with fly ashes and slag. The figure 21 shows that for the same w/b ratio the fly ash or slag addition meliorates this durability.

Resistance of the hardened cement pastes to sulfate solution attack is decreased with the CKD addition as partial PC substitute, too. In the Table 5, are shown the changes of the compression strengths of the hardened mortar specimens of different composition after being treated for three months in 5% Na_2SO_4 solution.

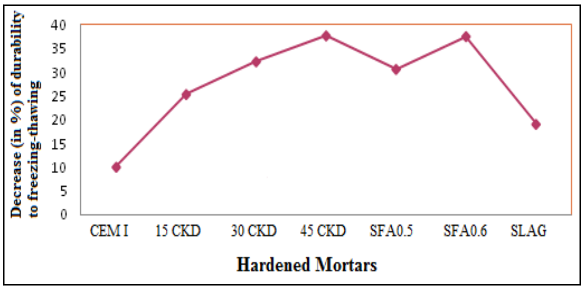

Figure 21 - Resistance to freezing and thawing of hardened mortars

From the results shown in table 5, we notice that the combinations PC-CKD-fly ash and PC-CKD-slag improved the sulfate resistance of the hardened mortar specimens. The compression strengths of SFA 0.5, SFA 0.6 and SLAG mortars hardened in sulfate environment did not decreased but continued to increase regardless the 15% CKD addition as PC partial replacement.

Table 5 - Changes (in %) of compression strength of cement pastes treated in sulfate solution

Specimen	CEM I	15 CKD	30 CKD	45 CKD	SFA 0.5	SFA 0.6	*SLAG*
Change of compression strength (in %)	*12.51*↑	*2.18*↓	*0.11*↓	*0.26*↓	*13.49*↑	*9.13*↑	*6.55*↑

In the Figure 22 are shown the results taken by mercury intrusion porosimetry, MPI, for the hardened mortars at the age of 9 months.

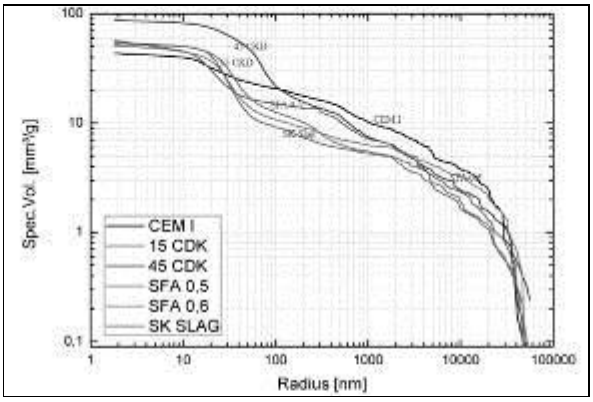

Figure 22 - Pore distribution curves

In the Figure 22, the pore size distribution data are presented in the form of cumulative pore diameter distribution curves, the pore volume parameter being expressed as mm^3 of pore space per gram of oven–dried sample. The data are cumulated from largest pore diameter measured (on the right hand-side of the figure) to the smallest diameter limit set by the pressurizing capacity of the instrument.

From the Figure 22 we notice that the total porosity of the control sample CEM I (44 mm^3/g) is the lowest whilst that of the sample 45 CKD (88 mm^3/g) is the highest. The other samples total porosities are at intermediate values of 50, 52, 55 and 57, respectively for the samples SFA 0.6, 15 CKD, SLAG and SFA 0.5. So, it is evident that the addition of 15% kiln dust increases the total porosity with only 8 mm^3/g or 18%, whereas with the addition of 45% of kiln dust as replacement of Portland cement the porosity of the hardened paste is doubled. The total porosity increase is considered to happen due to the high chloride content of the CKD (presence of this product enhances the crystallization of hydration products leading to an opening of the pore system)

The use of both fly ash and blast furnace slag and kiln dust does not effect visibly on the total porosities of hardened mortars.

The profiles of the six curves on the Figure 22, show that the pore size distribution is different for the sample CEM I and 45 CKD, compared with the four other samples, that have 15 % kiln dust with and/or without fly ash or furnace slag. It is evident that the volume of large pores in the sample CEM I is bigger than in other samples whilst in the sample 45 CKD the fine pores volume is bigger.

The replacement of Portland cement with fly ash in the sample SFA 0.5 increased the porosity of the hardened sample but decreased the average pore size compared with the sample 15 CKD. Improved sulfate resistance in SFA 0.5 samples (see Table 5), coincides with lower content of big pores in these hardened mortars and could be due to its influence.

The bigger pores in the hardened samples increase with the increase of water binder ratio although the total porosity may not increase. The added water in the sample SFA 0.6 helped to develop bigger pores in its hardened sample compared with the sample SFA 0.5 although the total porosity of the latest is higher.

CONCLUSION

- The Cement Kiln Dust have chemical, mineralogical and physical characteristics quite different from Portland cement. They vary depending on raw materials, type of kiln operation, dust collection systems, fuel type used in cement clinker production, etc.
- The CKD strength gain contribution in the CKD-PC blends is low. It seems that the CKD used has not self cementitious value due to the absence of calcium silicates and its low fineness.
- It is possible to use of the CKD as partial replacement of PC, in combination with pozzolanic materials, like fly ash, blast furnace slag, etc, in certain mortar mixed designs without lowering the main characteristics of the product.

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IZVOD

KARAKTERIZACIJA I KORIŠĆENJE PRAŠINE IZ CEMENTNE PEĆI (CKD) KAO DELIMIČNU ZAMENU PORTLAND CEMENTA U MALTERU I PROIZVODNJI BETONA

Prašina iz cementne peći (CKD) je nusproizvodni materijal u industriji cementa. Fizičko-hemijske karakteristike CKD zavise od sirovina, vrste rada peći, sistema za prikupljanje prašine i vrste goriva koje se koristi u proizvodnji klinker cementa. Slobodni kreč se nalazi u CKD. U zavisnosti od koncentracije kreča (CaO) i minerala cementa, CKD može da ima vrednost cementa.

Većina CKD se reciklira tako da se vraća nazad u cementnu peć kao sirovina. Od skora je trend da se CKD koristi za stabilizaciju zemljišta, tretman otpadnih voda, itd. U ovom radu je prikazan pokušaj korišćenja CKD kao delimičnu zamenu za portland cement u proizvodnji maltera i betona. CKD i Portland cement karakterisani su sa hemijskog, mineraloškog i fizičkog aspekta. Nekoliko smeša obavezujućih materijala su sastavljeni korišćenjem od 0 do 45% CKD kao delimičnu zamenu za Portland cement. Pored CKD, u nekim drugim smešama dodati su pepeo i šljaka iz visokih peći, takođe. Pripremljene smeše su proučavane u smislu njihovih osobina, kako u svežem tako i u očvrslom stanju. Testovi su sprovođeni u različitim vremenskim intervalima; ispitivana je njihova čvrstoća, trajnost i poroznost.

Ključne reči: *CKD, portland cement, karakterizacija, korišćenje*

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