Utilization of Cement Kiln Dust in Production of Alkali-Activated Clinker-Free Binders

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***Abstract* – During burning of Portland cement clinker, a large amount of both clinker and aspiration dust accumulates in electrostatic precipitators and rotary kilns; therefore, rational use of these products containing a certain portion of a complete raw material is an important task in the cement industry. It is noted that reuse of dust from electrostatic precipitators through recycling in the kiln is impossible, since it contains a high amount of alkali-containing impurities, and this will have a negative effect on the clinker quality. Therefore, the paper presents a practicable method of utilization of cement kiln dust in production of alkali-activated clinker-free binders and concrete based on these binders. The results obtained in the study of cement kiln dust are presented, and the energy dispersive and comparative analyses of the test powders are carried out. The results of chemical analysis are used to determine the relationship between oxides in the form of appropriate moduli and saturation factor. Recipes for alkali-activated binders are developed, and their properties are studied.**

Keywords – portland cement clinker; aspiration dust; electrostatic precipitator dust; alkali metals; dispersion; rotary kiln; dust emission.

I. Introduction

For many years, Portland cement has been considered a high-demand material in the construction industry. Its production and industrial consumption is growing rapidly from year to year, and it is an important indicator of the national economic development. However, according to the CPCB (Central Pollution Control Board) [1, 2], the production of Portland cement can be classified as hazardous production due to large amount of emissions into the environment. Emissions of different nature take place at almost all technological stages of cement production. Harmful substances contained in gas-air emissions include aspiration and clinker dust from rotary kilns, lime, large amounts of carbon dioxide and sulfur compounds, dioxins, etc.

Klinker burning rotary kilns are the main source of dust emission (30% of dust removal) due to the fact that the clinker burning process is based on the counterflow principle, when exhaust flue gases involve fine particles of the burning raw mixture into the flow. It has been found that production of a kilogram of clinker accounts for up to 7.5 m^3 of exhaust gases with a dust content of up to 70 g/m^3 [3.4]. However, in accordance with sanitary standards for industrial enterprises, the dust concentration in the indoor air should not exceed 0.04 mg/m^3, the carbon monoxide content in the air should not be higher than 0.03 mg/m^3, and that of hydrogen sulfide should not be more than 0.02 mg/m^3. In the air emitted into the atmosphere, the dust concentration should not exceed 0.06 mg/m^3, so that when dust is dispersed in the atmosphere outside the sanitary protection zone, the average daily dustiness should not exceed 0.15 mg/m^3 [11–15].

Thus, in order to prevent harmful emissions into the atmosphere and harmful effect on the environment and humanity, dust should be thoroughly removed from kiln gases when passing through the cleaning system. An effective dust collector can be considered as an electrostatic precipitator, the cleaning degree of which is 98–99%, with dust content at the inlet of 25–30%, and permissible dust concentration in emissions of 0.1–0.5 mg/m^3.

During burning of Portland cement clinker, a large amount of both clinker and aspiration dust accumulates in electrostatic precipitators and rotary kilns, therefore, rational use of these products containing a certain portion of a complete raw material is an important task in the cement industry [16–20]. It should be noted that recycling of dust from electrostatic precipitators through recovery in the kiln is impossible since it contains a certain amount of alkali-containing impurities, and this will negatively affect the clinker quality.

II. METHODS AND MATERIALS

Therefore, this paper presents a practicable method of cement kiln dust utilization to obtain alkali-activated clinker-free binders and concretes based on these. These methods could be developed since a cement plant in the Chechen Republic has been operating since 1974, and Portland cement clinker is burnt in two rotary kilns with a clinker productivity of 1200 tons per day [3, 21–24].

We have investigated cement kiln dust collected from electrostatic precipitators located in two different zones of the kiln. In the cold end of the kiln, the released dust is referred to as aspiration dust, and its composition is similar to the composition of the initial raw material mixture. In the final hot zone of the furnace, clinker dust is formed in the cooling sections and the clinker conveyor gallery. The clinker dust is sufficiently abrasive dark gray powder, the fineness of grinding determined by screening using sieve No. 008 showed a residue of 23%. Aspiration dust is light beige powder, much more dispersed than clinker dust, and the fineness of grinding showed a residue of 18%. The specific surface of the studied powders was investigated using the PSKH-12 instrument by air-permeability method. Table 1 shows the properties of the selected samples.

TABLE I. PROPERTIES OF DUST FROM ELECTROSTATIC PRECIPITATORS

No	Dust from electrostatic precipitators	True density, g/cm^3	Bulk density, g/cm^3	Fineness of grinding, m^2/kg
1	Aspiration dust	2.59	1.13	210
2	Clinker dust	3.12	1.24	280

Energy dispersive microanalysis of the test powders of dust from electrostatic precipitators collected using a Quanta 3D 200 i scanning electron microscope with an integrated Genesis Apex 2 EDS microanalysis system by EDAX showed similar chemical compositions of clinker and aspiration) dust with portland cement clinker and initial raw mixture, respectively. However, it should be noted that the content of alkali metal oxide K_2O in the aspiration dust sample is 6.43%, whereas in the clinker, it decreases to 1.57% (Table 2). This can be attributed to the fact that clinker dust was formed in the hot zone of solid-phase synthesis in the rotary kiln at 1300 °C and higher temperatures, where alkali metal oxides are burnt out and decomposed [5–8].

TABLE II. CHEMICAL COMPOSITION OF DUST FROM ELECTROSTATIC PRECIPITATORS

Oxide composition	Clinker dust	Aspiration dust
MgO	1.49	0.97
Al_2O_3	4.11	4.68
SiO_2	16.89	20.31
K_2O	1.57	6.43
CaO	71.64	64.15
Fe_2O_3	4.3	3.47

III. RESULTS

Micrographs taken with a scanning electron microscope allow a comparative analysis of the electrostatic dust structure. Clinker grains magnified 5000 times are represented by large volumetric particles with pronounced cleavage and small leaves. Clinker minerals can be clearly observed (Fig. 1). The analysis of micrographs of aspiration dust showed that the grains have a looser and porous structure; the initial stage of mineral formation can be observed (Fig. 2).

As noted earlier [4, 20–24], reuse of dust from electrostatic precipitators in the technological cycle is not reasonable, since chemical analysis confirms the presence of alkali metals, the content of which, according to GOST, is strictly limited to not more than 0.67%. Moreover, addition of aspiration dust to the raw material mixture leads to the sludge thickening, which complicates its transportation to the feeders of rotary kilns.

To perform the comparative analysis and to study the compressive strength of cement kiln dust, the ratios between oxides in the form of appropriate modules and saturation factors (Table 3) were determined based on the results of chemical analysis; the clinker by the Chiri-Yurt plant was taken as a control sample.

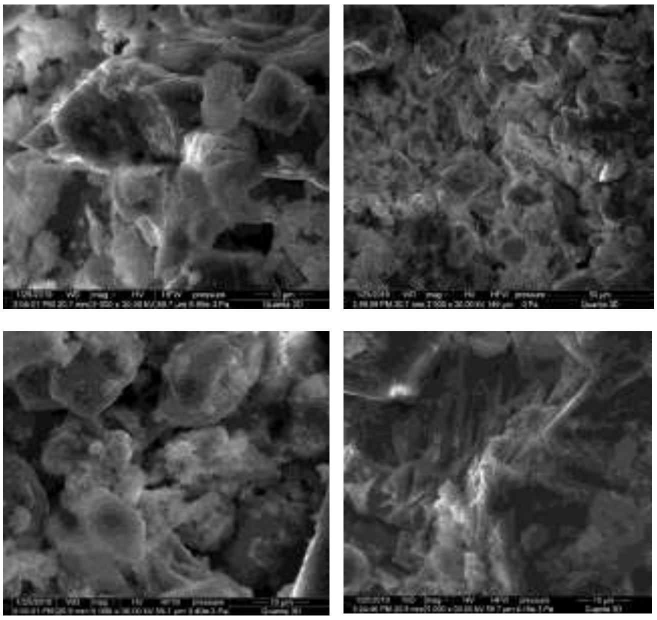

Fig. 1. Micrographs of clinker dust grains at different magnification

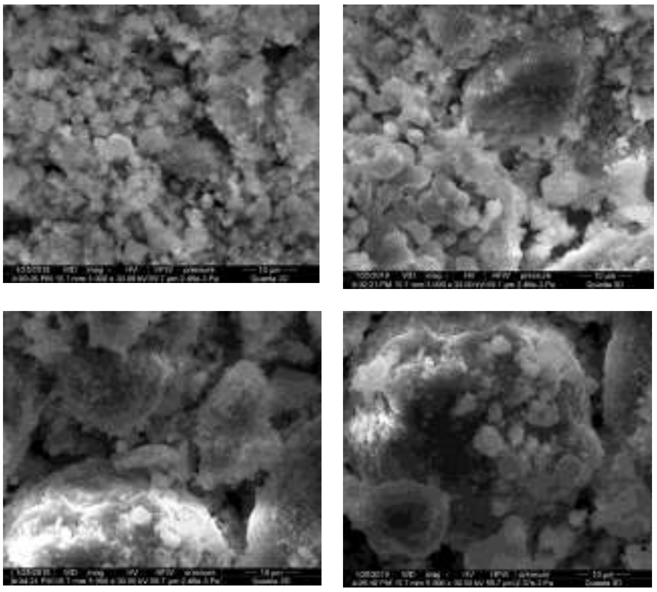

Fig. 2. Micrographs of aspiration dust grains at different magnification

The obtained modular characteristics of the studied powders showed that they significantly differ from the clinker characteristics. The saturation factor was observed to increase. It was established that saturation factor of industrial clinkers is in the range of 0.85–0.95. Higher values indicate the increased content of tricalcium silicate and different terms of stiffening and heat release during mineral hydration.

TABLE III. MODULAR CHARACTERISTICS OF POWDERS STUDIED

Material	**Moduli**		
	saturation factor *SF*	**silica modulus *n***	**alumina modulus *p***
Aspiration dust	1.30	1.8	1.08
Clinker dust	0.98	2.6	1.18
Clinker	0.92	2.2	1.30

The silica modulus, which indicates the presence of silicate minerals and fluxes, varies from 1.7 to 3.5 for common Portland cement clinker. The alumina modulus, which presents the ratio of fluxes in the clinker, is in the range of 1–2.5. The obtained results show that the moduli of cement kiln dust clearly characterize the source of its formation in a specific burning zone, which was confirmed by energy dispersive microanalysis.

This study proposes a practicable technique to use cement kiln dust, that is, to obtain alkali-activated clinker-free cements. Clinker and aspiration dusts were used to prepare test beams of 40x40x160 mm in size from the mixture of cement kiln dust (480 kg), quartz sand from the Chervlenskoye deposit (1440 kg) mixed at a ratio of 1:3, and volcanic ash (50 kg). Mixing was carried out with liquid glass and silica modulus of 2.8 with a density of 1.24 g/cm^3, and a highly concentrated alkaline solution of sodium hydroxide. Alkaline activator consumption was 120–128 liters. After one day, the prepared samples were removed from the forms and dried in a drying cabinet at 40 °C for a couple of days. Next, the samples were placed in water for 28 days for maturation. It should be noted that water in the vessel was replaced with clean water during the first three days due to the process of leaching. Recipes and characteristics of the obtained binders are shown in Table 4.

TABLE IV. RECIPES AND PROPERTIES OF ALKALI-ACTIVATED BINDERS

Properties of binders	**Cement kiln dust**	
	clinker dust	***aspiration dust***
grouting fluid– liquid glass		
AS/CD	0.25	0.26
Start of setting min	34	26
End of setting, min	45	42
Average density, kg/m^3	2090	2080
Water absorption, %	4.2	5.3
Compressive strength, MPa:		
7 d	32.5	24.1
28 d	68.7	49.6
grouting fluid – sodium hydroxide		
AS/CKD	0.26	0.27
Start of setting g, min	38	30
End of setting, min	55	54
Average density, kg/m^3	2100	2110
Water absorption, %	5.1	5.6
Compressive strength, MPa:		
7 d	22.7	17.2
28 d	41.6	26.5

[a] Note: AS – alkaline solution; CKD – cement kiln dust

The study results showed that the use of alkali-activated cement kiln dust will enable the production of cement stone with high strength properties. On the 28th day, samples of clinker dust mixed with sodium metasilicate and samples of aspiration dust showed compressive strength of 68.7 MPa and 49.6 MPa, respectively. Caustic soda used as an alkaline activator showed significantly lower values of 41.6 MPa and 26.5 MPa, respectively. Therefore, alkaline activator directly affects the properties of alkali-activated binders.

IV. CONCLUSION

The analysis of the use of cement industry waste, namely clinker and aspiration dust, showed that daily emissions of dust into the atmosphere contribute to the environmental pollution. In addition, the amount of dust caught by electrostatic precipitators needs to be stored and thus requires some land areas, which will definitely harm people working in this industry or living nearby.

Therefore, it is necessary to rationally use cement kiln dust in the production of alkali-activated binders, and the resulting strength of cement stone obtained confirm the effectiveness of this method [9, 10].

Thus, the proposed method for cement kiln dust utilization will make it possible to partially replace expensive and power-consuming Portland cement in the construction industry.

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