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Oil Shale Ash as a Substitutional Green Component in Cement Production

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ABSTRACT

The energy crisis is one of the major challenges confronting the cement industry today. Although non-renewable energy sources are becoming scarce, the presence of significant quantities of oil shale indicates its continued use as an energy source in the cement industry. However, significant environmental impacts may occur as a result of the large amount of oil shale ash (OSA). As a result, the researchers are investigating alternative methods for recycling and reusing the OSA in a variety of applications. The purpose of this work was to use OSA as a green substitute component in cement production due to its high calcium oxide (CaO) content, which is the major component of cement clinkers. The chemical composition of OSA and Clinker samples were determined using X-ray fluorescence (XRF) and X-ray diffraction (XRD). OSA and clinker samples were combined in various ratios and then ground in a ball mill to obtain the desired grain size. The new blended products were prepared and tested at Lafarge factory's laboratories. The results indicated that by adding 10% of OSA to the clinker, the mixed product performed better than the reference sample. Additionally, using this percentage of OSA results in a 45% reduction in the power consumption of the grinding process compared to the reference sample.

Keywords: cement production, oil shale ash, power reduction. green environment, clinker.

INTRODUCTION

The oil shale ash (OSA) is the residual product of the direct burning of the oil shale [1]. This ash becomes more accepted as sub-alternative material in several industrial products manufacturing; especially in the ceramics, water treatment plants and construction materials [2–6] The latter use received massive interests in the last decade with the focus on the cement partial replacement in concrete [7–9]. Such replacement promotes reducing the need of high cement ratio in concrete with insignificant differences in the mechanical properties [8]. The percentages of the OSA replacement in cement vary between 10-30 percent [3, 7]. These percentages along with mixing amounts will lead to different cement mixture and, thus, different mechanical properties [6]. Another research paper suggested up to 15% OSA replacement to produce typical Portland cement clinker. Other approaches indicated that a 20% replacement of the OSA in the ordinary Portland cement boosted the mechanical properties [10]. However, opposite results obtained in other cement products, such as the mortar cement, where the compressive strength decreased when they assigned OSA replacement at higher percentages [7]. In other concrete types, Concrete FloorBoxing, the OSA content may vary between 20 and 80 percent and can be used for filling purposes [11].

Chemically, the OSA contains high calcium oxide content that is, naturally, suitable for cement production itself [6, 12]. In addition, OSA also contains SiO_2 and Al_2O_3 that both can demonstrate pozzolanic activity (6). Nevertheless, OSA grain size is determinant in the efficiency of OSA replacement. The smaller OSA grain-size exhibits greater particle surface area that enhances self-cementing properties [6]. Concordantly, the advantage of using OSA in cement and concrete production is the relatively low grounding power needed. Its small solid particle does not need the same grinding power as the lime and other components.

The Jordanian oil shale localized in at least eight areas. The oil content in this shale varies between 6.5 and 11 wt% and the total oil shale reserve is about 50 billion ton [3]. Currently, The Attarat Area hosting the first power plant in Jordan that use the oil shale in generating electricity with a total production of 470 MW [13]. The oil shale of this area contains 11 wt% oil and hosted in 45 m thick layer [14]. The anticipated vast production of the OSA will begin by the commissioning of this plant. Therefore, thousands of tons of OSA offer new raw material for the production of both the clinkers and OPC. From environmental point of view, maximizing the usage of OSA in cement and concrete production would give powerful help in disposing the mounds of OSA in the power plant storage yards.

This work aims to evaluate the usage of OSA as a green substitute component in cement production to reduce the possible environmental impacts and also to increase the performance of new product that produced by mixing the OSA with clinker. This work presents an experimental-based proofs of the adequacy of partial replacement of ordinary cement by Jordanian-OSA in the cement production.

METHODS

Samples characterization

As shown in Figure 1, representative samples of OSA and clinker were provided from the Ministry of Energy & Mineral Resources and Lafarge Jordan Cement, respectively. X-ray fluorescence and X-ray diffraction were used to investigate the chemical compositions of OSA and clinker samples. As shown in the Figure 2a, five random samples of OSA were analysand using XRF to verify the mineral contents. Two major minerals were detected in the OSA samples: calcium oxide and quartz (SiO_2). Figure 2b presents the XRD analysis for the OSA samples, As shown, five minerals were detected: limestone ($CaCO_3$), anhydrite ($CaSO_4$), quartz (SiO_2), kaolinite ($Al_2Si_2O_5(OH)_4$), and magnetite (Fe_3O_4). Besides that, a comparison study between OSA samples and clinker samples were studied as shown in Table 1. The results show that a significant similarity in the ratios of mineral content between OSA and clinker. For example, the CaO content in OSA was 46.2% compared to 67.5% in the clinker. These results lead to that there is

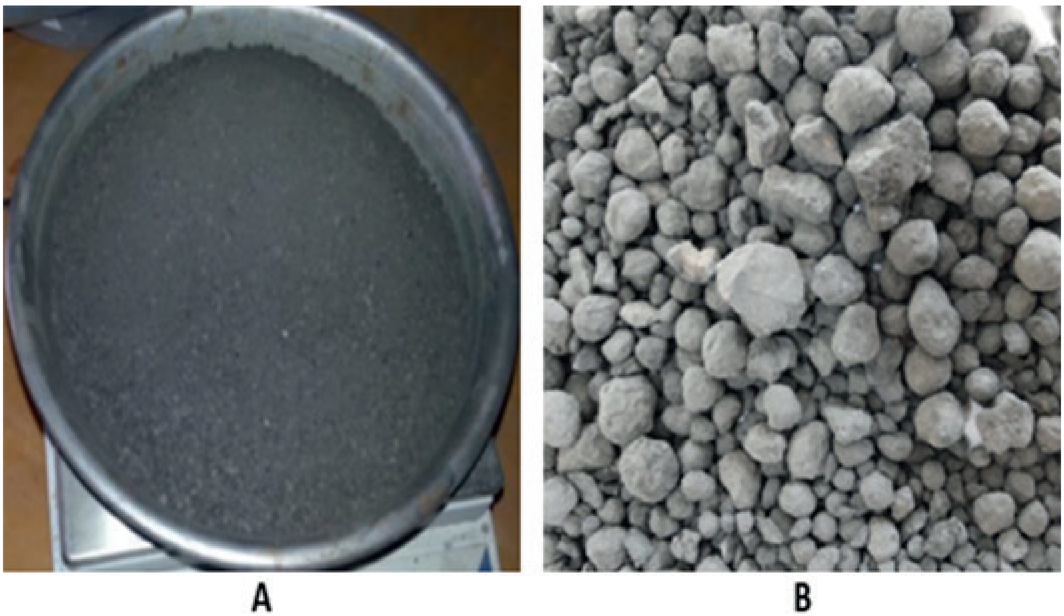

Figure 1. a) OSA sample; b) clinker sample

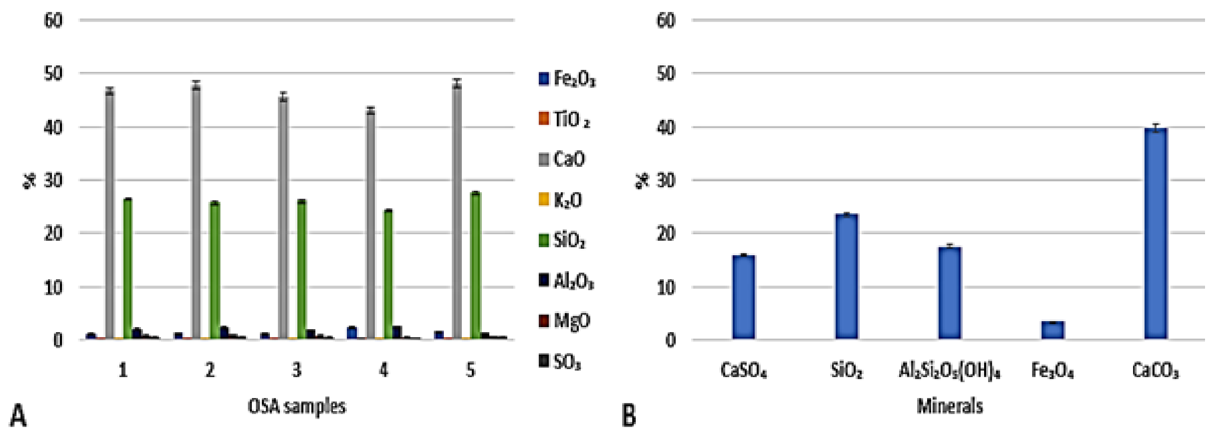

Figure 2. a) XRF analysis for OSA samples; b) XRD analysis for OSA samples

a very high possibility of using this tailing ash as a substitute material at specific ration in the cement production.

Design of experiments

One of the cement products at Lafarge Jordan Cement called "Alrasekh" contains 96% clinker and 4% gypsum. In this part of work, a set of experiments were performed by replacing the clinker to OSA at different ratios starting from 0% (baseline experiment) to 96% without changing in gypsum rate to investigate OSA-Alrasekh cement. Table 2 shows ten experiments were prepared to obtain a 1000 gram of mixed OSA-Alrasekh cement to carry out the necessary laboratory tests to examine the mixed-product. Three samples of each mixed OSA-Alrasekh cement product were prepared to ensure the accuracy of results.

Laboratory tests

Laboratory tests such as degree of plane and compressive strength were conducted for all the 30 samples to evaluate the performance of mixed-product and compared it with the baseline "Alrasekh". All the laboratory tests were performed at Lafarge Jordan Cement laboratories. The degree of plane which is the surface area of 1 sq cm per one gram of the samples. And the compressive strength is the amount of force acting on the surface at 2, 7 and 28 days.

Table 1. A comparison study between OSA samples and Clinker samples

Sample	Fe_2O_3 iron (III) oxide	TiO_2 titanium dioxide	CaO calcium oxide	K_2O potassium oxide	SiO_2 silicon dioxide	Al_2O_3 aluminum oxide	MgO magnesium oxide	SO_3 sulfur trioxide
Oil shale ash (OSA)	1.47	0.11	46.2	0.08	25.9	1.9	0.74	0.47
Clinker	2.9	0.17	67.5	0.17	21.6	4.9	2.09	0.67

Table 2. The experiments design that performed during this study

Sample	OSA %	OSA (g)	Clinker (g)	Gypsum(g)	Total weight (g)
Baseline	0	0	960	40	1000
1	10	100	860	40	1000
2	20	200	760	40	1000
3	30	300	660	40	1000
4	40	400	560	40	1000
5	50	500	460	40	1000
6	60	600	360	40	1000
7	70	700	260	40	1000
8	80	800	160	40	1000
9	90	900	60	40	1000
10	96	960	0	40	1000

Power requirement

The marketable grain size of cement particles is within 7 ~ 200 µm. The amount of power consumed to grind the samples to be within that range was calculated using the following equation (Eq. 1).

$$P = n * t * factor \tag{1}$$

where: P – amount of power kWt/ton;
n – the number of cycles per minute rpm;
t – grinding time;
f – factor constant 0.0142.

RESULTS AND DISCUSSION

Degree of plane

The degree of plane is the surface area of 1 sq cm per one gram of the samples. The mixed samples were grinded using a laboratory ball mill at 45 rpm to obtain the average degree of plane 3800 ± 100cm^2/g. Figure 3 shows the degree of plane for all samples. For example, at 10% OSA with 86% clinker and 4% gypsum, the degree of plane was 3865 cm^2/g compared to 3850 cm^2/g for the baseline sample. The reason for the increase in degree of plane is due to the increase in the percentage of OSA content in each sample. Since the average particle size of OSA was determined at 250 microns, that helps to have good performance of grinding process.

Compressive strength

All mixed samples as they presented in Table 2 were prepared and concreted to evaluate the performance of mixed-product and compared it with the baseline "Alrasekh". A special sand was used based on the European standards that Lafarge Jordan Cement follows in examining their products. Compressive strength tests were conducted at 2, 7, 28 days. Figure 4 shows the amount of compressive strength for only the first 5 samples because the samples that contain more than 50% of OSA were poorly textures. As shown, the sample that contain 10% OSA, 86% clinker, and 4% gypsum had high compressive strength in all day's tests. It had 36.9 MPa, 46.9 MPa, 58.9 MPa for 2 days, 7 days, and 28 days, respectively. These values indicated that the capacity of OSA cement at 10% to withstand loads before failure is higher than the baseline sample. These results indicated that increasing the OSA content in the sample leads to decreasing the compressive strength due to the reduction in the size of pore openings in the OSA-mixed samples.

Power requirement

The grinding time was recorded for each sample to calculate the power requirements to grind the samples to be at the range of plane. As shown in Figure 5, 65 min was needed to grind the baseline sample to obtain the 3850 cm^2/g, which repiques a lot of power almost 44 kW/ton compared to OSA-Alrasekh samples. When 10% of OSA was added to 86% of Clinker and 4% of Gypsum, the fine particles size of OSA helps to reduce the power requirement in grinding process. The total power was almost 24.4 kW/ton which almost 45% lower than the power requirement to grind the baseline. Same as same when the percentage

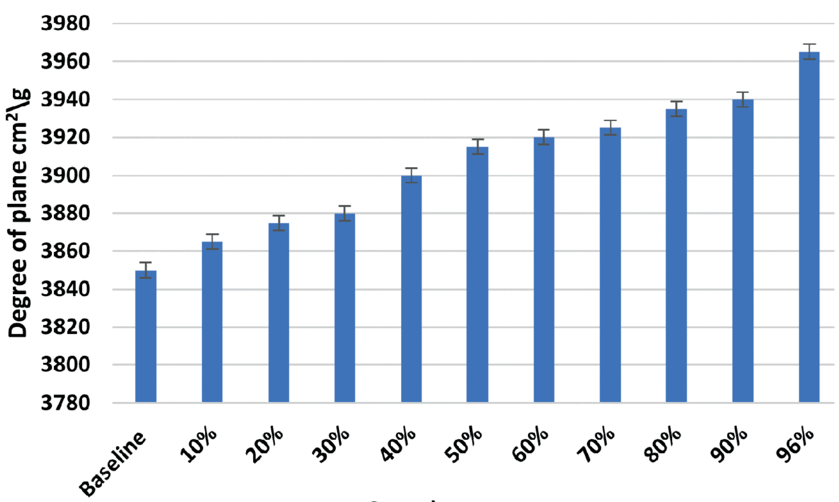

Figure 3. The degree of plane for all samples cm2\g

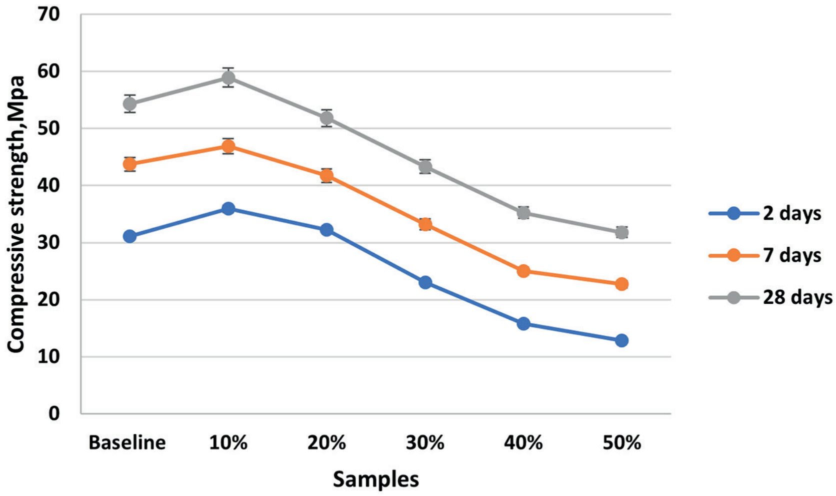

Figure 4. The compressive strength for the first 6 samples in 2 days, 7 days, and 28 days

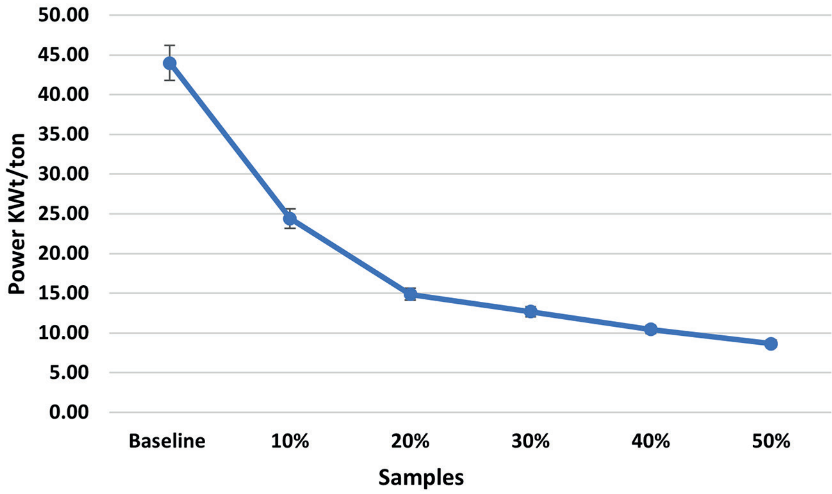

Figure 5. The power requirements to grind the samples

of OSA increased the total power was reduced compared to the baseline sample. Therefore, the advantage of utilizing OSA is the comparatively low grounding power required because to its tiny solid particle, which does not require the same grinding power as lime and other components.

CONCLUSIONS

Oil shale ash were used as a substitutional green component in cement production due to its high calcium oxide in its chemical composition, which is the major component in cement clinkers. High performance product was obtained by adding 10% of OSA to 86% clinker and 4% gypsum compared to the reference sample (96% clinker and 4% gypsum). High compressive strength was recorded at that ratio (58.9 MPa) compared to the reference sample (54.3 MPa). Since the average particle size of OSA is smaller than clinker, using 10% of OSA will help the grinding process and make it faster than the refence sample which led to reduce the power consumption to almost 45% in grinding process. Using the OSA as another source of raw cement materials increases the economic and reduces environmental impact. For example, to produce one ton of reference sample, it needs 1.7 ton of raw materials. But when 10% of OSA was added, it needs only 1.53 ton of raw materials to produce high quality cement product.

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