

BEHAVIOR OF CONCRETE MADE USING OIL SHALE ASH AND CEMENT MIXTURES

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This paper presents an experimental study on mechanical and thermal properties of concrete made from oil shale ash, cement and sand and/or aggregate mixtures. The properties determined were compressive strength and thermal conductivity of the concrete mixtures. The used ash was obtained by direct combustion of Sultani oil shale. The composition of ash is close to that of Estonian oil shale ash. Thirty-two cubes and twelve cylindrical samples were prepared to conduct compression and thermal conductivity tests, respectively. The cure duration for the cubes was 1, 7, 14, and 28 days, for the cylinders – 28 days. The content of ash in binder was 10, 20, and 30% for compression and 10, 20, 30, 60, and 70% for thermal tests. The weight ratios of cement:aggregate, cement:sand and water:binder were 1:4.5, 1:3 and 1:2.5, respectively, kept constant for each sample. The results are compared with the corresponding data for concrete made without oil shale ash. The results show that compressive strength decreases with increasing proportion of ash in the mixtures and increases with increasing curing time for all cases. Thermal conductivity of concrete samples decreases with increasing content of ash in the mixtures.

Introduction

The major problem the world is facing today is the energy crisis. One important prospective source of energy in the world is oil shale. The world's known reserves of oil shale are vast, being many times greater than the proven remaining resources of crude oil and natural gas [1]. However, due to higher cost required for mining and extraction energy from oil shale, as compared to petroleum-based crude oil, only a few oil shale deposits are exploited in Estonia, China, Brazil, Russia and USA to yield shale oil and to

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generate electric power. Jordan with estimated reserves of 50 billion tonnes is increasingly considering oil shale an alternative energy source [2].

Preliminary studies on Jordan oil shale began in 1966 by the Natural Resource Authority. Recently the Government of Jordan (GOJ) throughout the Ministry of Energy and Mineral Resources, Natural Resource Authority, and Jordan Electric Authority in collaboration with many specialized international companies, has completed extensive studies directed toward the use of oil shale. The studies include geological, techno-economic, pre-feasibility exploitation, and testing of oil shale in pilot plants. The results of the studies prove the applicability of Jordanian oil shale at using both processing technologies: retorting for oil production and direct combustion for power generation.

Oil shale deposits are widely distributed all over Jordan lying in the area of about 60% of the territory (Fig. 1). There are twenty-four known deposits of oil shale discovered in several parts of Jordan. The main deposits are concentrated in the central part, and classified as shallow and near the surface. These deposits are suitable for open-pit mining. Seven of them have been investigated in details. Other deposits are located in northern and eastern parts of the country, and classified as lying deeper and suitable for underground mining.

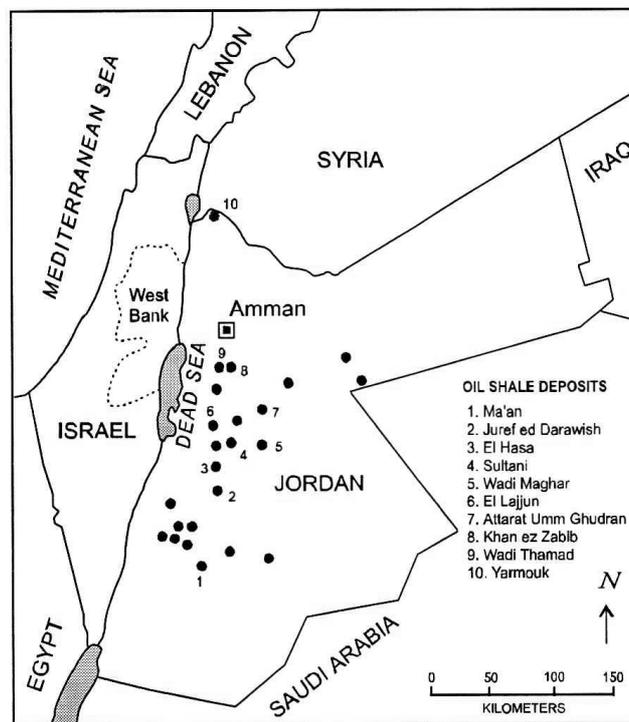


Fig. 1. Oil shale deposits in Jordan

Sultani deposit has been selected for this study, because it offers good conditions for retorting and direct combustion. Moreover, the Government of Jordan looks to build an oil shale-fired power plant of capacity 100–300 MW in this area.

The most important properties of Sultani oil shale are: low calorific value – 3450 kcal/kg; an average oil content of 9.4%; and an ash content of 70%. Thus, the energy content and the oil yield are too low and the amount of ash is too large. Therefore the utilization of only oil shale energy is not economical. Accordingly, a more economic utilization of oil shale can be achieved by using both oil shale energy and oil shale ash (OSA).

There are different ways to utilize OSA, mainly as a construction material, soil stabilizer and fertilizer for liming acid soil, foundry cores, supplement to animal food, etc. Presently the most effective way is using of OSA as a feedstock for cement production. This kind of application was employed in Estonia, Germany, and China. In Dotternhausen, Germany, for example, clinker (raw meal and oil shale) from the rotary kiln and hydraulic burnt shale from fluidised bed combustion unit together are used to produce Portland-burnt shale cement [3].

Studies carried out by Kikas [4], Kikas with coworkers [5], and Hanni [6] showed that the addition of about 30% OSA into Portland cement clinker can enhance compressive strength of the ordinary Portland cement. Kikas and coworkers [5] studying the influence of OSA on the properties of self-stressing shale ash cement concluded that the concrete made with burnt shale possesses high strength, high frost resistance, and low permeability.

However, little effort has been done to determine thermal conductivity of OSA in order to use it as an insulating material in building structure.

Khraisha [7] and Karim and Hanafi [8] measured effective thermal conductivity of Sultani oil shale and Athabascat oil sands and found that conductivity increases with increasing oil content and decreases with increasing temperature. However, the study conducted by Rezaei et al [9] on thermal conductivity of coal ash and slag samples shows that conductivity increases as temperature increases and porosity decreases.

The aim of this study is focused on experimental investigation of thermal and mechanical properties of concrete mixtures containing OSA as an additive material to the ordinary Portland cement. Thermal conductivity and compressive strength of concrete mixtures have been measured.

Used Materials

The cement used in this investigation was ordinary Portland cement obtained from the Jordan cement industry. The cement can be classified as CEM-11/A-P, 42.50 according to the Jordan specification.

Oil shale was obtained from the Sultani deposit. The ore was crushed and sieved to a nominal size of $1.2 < D < 2.4$ mm.

OSA was obtained by combustion of oil shale. The combustion process was performed using a special block designed from brick kilns and a combustion furnace type (Pottery Crafts, Ceradel Socor, Limoges-France). The maximum temperature of the furnace is 1300 °C. The combustion process is controlled by a voltage regulator at a temperature of 800 °C. This is the optimum temperature to achieve the best properties of the OSA; i.e. the maximum strength [3]. As a result of combustion, about 0.74 kg of OSA is produced per kg oil shale.

The sample of OSA was analysed on its chemical properties using X-RAY Fluorescence Analyser Type Diano-2023. The results are presented in Table 1. The analysis shows that ash contains 1.33 wt.% residual unburnt carbon.

Table 1. Chemical composition of OSA and raw matter of cement

Components	Oil shale ash, %		Cement, %
	Jordanian	Estonian*	
CaO	49.72	46–58	60–69
SiO ₂	30.97	20–28	18–24
Al ₂ O ₃	4.71	6–8	4–8
Fe ₂ O ₃	1.71	4–6	1.0–8.0
MgO	0.01	3–4	<5
K ₂ O	0.65	1–2	<2
Na ₂ O	0.43	0.1	–
TiO ₂	0.17	0.4–0.5	–
MnO	0.01	–	–
P ₂ O ₅	5.71	–	0-1

* Hanni [6]

Preparation and casting of test specimens

Two reference samples of ordinary Portland cement and eight samples of OSA-cement concrete mixtures were made. All the concrete mixtures were mixed for 5 min in a laboratory counter-current mixer. The weight ratios of cement:aggregate, cement:sand and water:binder were 1:4.5, 1:3 and 1:2.5, respectively, kept constant for each sample. The binder is taken as the sum of cement and ash. The proportions of the concrete mixtures are given in Table 2.

Thirty two 70×70×70-mm cubes and twelve cylinders with 25-mm diameter and 5-mm thickness were cast from concrete mixtures number 1 to 4, and 5 to 10, respectively. The cubes were used for determination of compressive strength, and the cylinders were used for determination of thermal conductivity of the mixtures. The cubes were cast in wooden moulds, remoulded after 24 ± 1 h. Thereafter they were wrapped in burlap and kept in a moist curing room at constant temperature 25 ± 2 °C and 100% relative humidity up to the day of testing. The cylinders were cast in steel moulds, and the same curing method was adopted for 28 days.

Table 2. Composition of concrete mixtures

Batch number	Cement, g	OSA, g	Ash content of binder, %	Aggregate, g		Sand ^{***} , g
				Fine [*]	Coarse ^{**}	
1	500	0.0	0.0	750	1500	–
2	450	50	10	750	1500	–
3	400	100	20	750	1500	–
4	350	150	30	750	1500	–
5	50	0.0	0.0	–	–	150
6	45	5	10	–	–	150
7	40	10	20	–	–	150
8	35	15	30	–	–	150
9	20	30	60	–	–	150
10	15	35	70	–	–	150

* (4.5 < D < 9.5) mm, ** (9.5 < D < 12.5) mm, *** (0.15 < D < 2.5) mm

Experimental set up and procedure

Experimental work was conducted on OSA without undergoing any chemical and/or further thermal treatment. Thirty two concrete cubes (eight for each age) were made from mixtures containing 0, 10, 20, and 30% ash in binder for determination compressive strength at the age of 1, 7, 14, and 28 days. Additionally, twelve specimens with 0, 10, 20, 30, 60, and 70% ash in binder were made for determination thermal conductivity at the age of 28 days.

The Universal Testing Machine was used to measure compressive strength of the concrete specimens. Cubes were compressed after 1, 7, 14, and 28 days of curing. The recorded compressive strength is the average of two cubes for each age.

Thermal conductivity was measured using the Hilton heat conduction unit of the type H 940. This unit is comprised of a brass heat source section (1) fitted with an electrical heater; a brass heat sink section (2) cooled at one end by running water (4); the intermediate section where the tested specimen is fixed (3), and a control panel. The sections 1 and 2 may be clamped together to form a continuous brass bar of the diameter 25 mm with six (three for each sector) temperature sensors located at 10-mm intervals. The equipment set up is shown in Fig. 2.

In order to fix the specimen under testing in the Hilton unit a mould from Teflon material was used with dimensions similar to the inside diameter (25 mm) of the brass bar. The specimen of a concrete mixture was inserted into the mould and together with it clamped between section 1 and section 2 to be ready for the experiment. Thermal conductivity of each specimen was investigated at different heat input (power supply) ranged from 1.5 to 10.5 W by an increment of 1.5 W. For each testing case sufficient time was given to achieve the steady-state condition, and then the temperature at all sensor points was recorded.

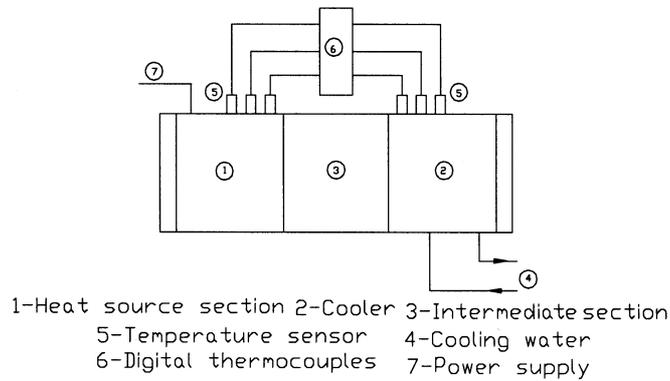


Fig. 2. Schematic diagram of the heat conduction unit H940 (Linear module).

Results and discussion

Oil shale ash

The characteristics of OSA as compared with the Estonian oil shale ash and cement raw material are shown in Table 1. From this table, one can see that OSA composition is favourable for cement production. However, phosphorous content exceeds the permissible one. On the other hand, the values of OSA components are close to the Estonian oil shale ash [6].

Compressive strength

The effect of OSA content on compressive strength of concrete mixtures can be established by comparing the measured values of strength of mixtures for a given curing time and percentage of ash. Figure 3 shows compressive strength

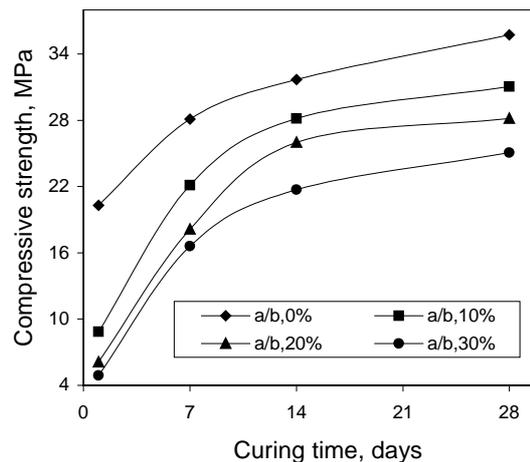


Fig. 3. Compressive strength of various concrete mixtures as a function of curing time

as a function of curing time. As shown in the figure, compressive strength increases with increasing curing time for all concrete mixtures. Furthermore, it is clear that compressive strength of OSA mixtures increases over a longer period of time than that of mixtures containing 0% OSA. The gain in strength between 1 and 28 days is 21.2 and 20.2 MPa for the mixtures with ash content of binder 10 and 30%, respectively. In Fig. 4, compressive strength of mixtures measured after 1, 7, 14, and 28 days is plotted against ash amount in binder. One can see that compressive strength decreases with increasing ash content in the concrete mixtures, and the highest strength of mixtures containing OSA is achieved at the age of 28 days.

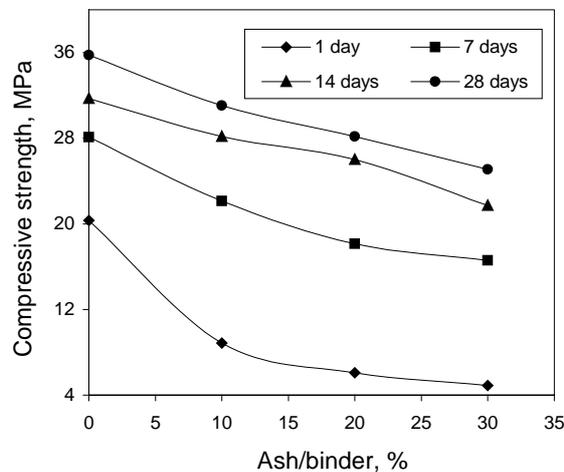


Fig. 4. Compressive strength of various concrete mixtures as a function of ash content in binder

Thermal conductivity

Thermal conductivity of the concrete mixtures containing OSA is plotted against ash content in binder and heat input. Also development of thermal conductivity of the concrete mixtures without OSA is shown for comparison. As shown in Fig. 5, thermal conductivity of the concrete mixtures decreases with increasing ash amount, and reaches its minimum value 1.18 W/m·K at 70% ash in binder and 1.5 W heat input. However, the minimum value - 1.7 W/m·K was measured for the concrete specimen with no ash at the same temperature (heat input). On the other hand, as shown in Fig. 6 thermal conductivity of the concrete increases with increasing heat input for all mixtures. The highest and the smallest values were obtained with 0% and 70% ash in binder, respectively.

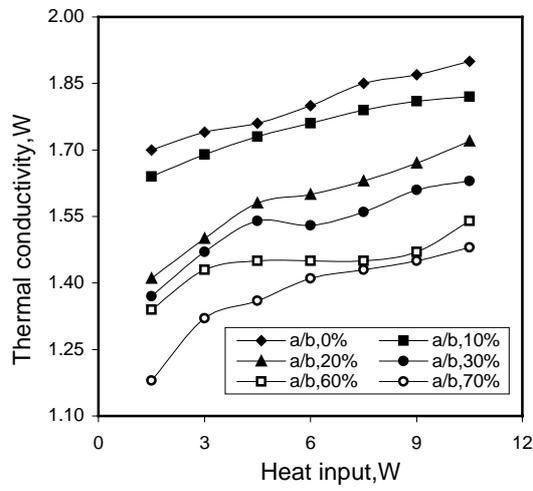


Fig. 5. Thermal conductivity of various concrete mixtures versus ash content in binder

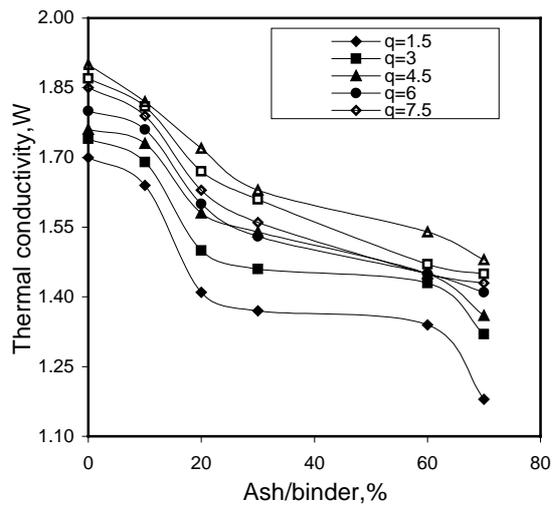


Fig. 6. Thermal conductivity of various concrete mixtures versus heat input

Conclusions

Basing on the results of measurements of compressive strength and thermal conductivity of the concrete mixtures obtained experimentally, the following can be concluded:

- The higher is the level of cement replacement by OSA, the lower is the compressive strength.
- The longer is the curing period, the higher is the increase in compressive strength.
- Replacing cement with ash, even with small amounts, is an effective way to improve thermal conductivity of concrete mixtures.
- As a result of combustion, about 0.74 kg of OSA is produced per kg oil shale. Therefore, utilization of OSA in cement is beneficial from both points of view: environment protection and improvement of the economics of oil shale exploitation.

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