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The Effect of Partial Replacement of Cement by Virgin Oil Shale Powder and/or Oil Shale Ash on Properties of Cement Mortar (Comparative Study)

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Abstract: In this research, a virgin Oil Shale Powder (OSP) and Oil Shale Ash (OSA) were used as an admixture of cement. The main aim of this study is to compare the compressive strength and setting time properties of mortar mix between the Oil Shale Ash (OSA) and the Virgin Oil Shale Powder (OSP). Results showed that the compressive strength of mortar cubes containing 10, 20 and 30% OSA decreased by 7.9, 15.8 and 31.6% of reference cement mortar cubes, respectively after 7 days and also decreased by 6.7, 11.1 and 24.4% of reference cement mortar cubes, respectively after 28 days curing compared with strength reference cement mortar cubes. While the strength of mortar cubes containing 10-30% OSP decreased by 21.0, 34.2 and 47.4%, respectively after 7 days curing compared to the strength of reference cubes and decreased by 15.6, 28.9 and 37.8% , respectively after 28 days curing. The reason of decreasing the compressive strength of cement mortar with OSA and/or OSP comparing with pure cement mortar is due to the lower content of ferrous component of OSA and/or OSP in their chemical compositions formulation. The greater reduction in compressive strength of cement with version OSP comparing with OSA is due to the existed oil in the voids of OSP. Setting time of cement paste increased by (23-28), (35-38) and (55-60) min when use cement mortar with 10, 20 and 30% OSA and/or OSP comparing with pure cement mortar due to the slow hydration of cement with OSA and/or OSP. The results of the conducted experiment proved the possibility of reuse oil shale ash as replacement in ratios up to 20% without causing significant effects on the studied properties of cement. The presence of shale in mortar enhances the composite material properties. The results showed an improvement when using cement with OSA or OSP in long time curing.

Key words: Virgin oil shale, oil shale ash, cement mortar, compressive strength, setting time, formulation

INTRODUCTION

The slow progress in using virgin Oil Shale Powder (OSP) as alternative source of oil, especially in developing countries such as Jordan, led to a number of investigations in the area of using OSP as a raw material in producing some building materials. Also mining and extraction of energy from oil shale will produce huge amounts of Oil Shale Ash (OSA) after burning. Disposal of the expected high daily production amounts of OSA is expensive and is normally associated with serious environmental problems. Therefore, investigations should be conducted to provide safe disposal and re-use of OSA. Partial replacement of Ordinary Portland Cement (OPC) by OSA or virgin OSP in manufacturing a cement mortar may improve some of its properties. The effect of partial replacement of cement by oil shale ash on the compressive strength and setting time of cement paste has been studied. There are different ways to utilize OSP and 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. The total amount of OSA formed is about 50% of the fuel mass. Oil shale ash is formed from solid fuel mineral matter in the amount which depends on the combustion temperature and other conditions. Besides the release of free oxides in the combustion process, the decomposition of oil shale causes the formation of new chemical compounds. The type and amount of these compounds depend directly on the characteristics of the combustion process. In spite of the long-term research of reusability options, most of OSA is still deposited in ash sediment fields next to the power plants. Deposits of OSA cause serious landscape modifications in the area surrounding the power plants which use oil shale as fuel. In the atmospheric conditions a number of transformations take place including carbonation of free CaO, hydration of calcium silicates, calcium aluminates and calcium ferrites which provoke hardening and ash stone formation at deposits.

Literature review: Previous experimental studies of the use of oil shale ash in cements have been carried out by

Al-Hamaiedeh *et al*. (2010), also a lot of researches were conducted in the Federal Republic of Germany FRG, the United States, China, the (former) USSR and Jordan. The work in the FRG and in the USSR has been reported only by Wuhrer (1950), respectively. A review study by the Federal Republic of Germany and the United States. The Jordanian study is easily available and very informative. This kind of application was employed in Estonia, Germany and China. In Germany, for example, clinker from the rotary kiln and hydraulic burnt shale from fluidized bed combustion unit together are used to produce Portland-burnt shale cement studies carried out by Kikas *et al*. (1986) and Hanni (1996) showed that the addition of about 30% OSA into Portland cement clinker can enhance compressive strength of the ordinary Portland cement. Kikas *et al*. (1986) 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. Partial replacement of Ordinary Portland Cement OPC by OSA or OSP in concrete mixes and its effect on the compressive strength of concrete has been reported indifferent studies. AL-Hasan (2006), Alabadan *et al*. (2006), Sengul *et al*. (2005), Mahmud *et al*. (2005). The results of the above research studies show that partial replacement of OPC in concrete mixes by OSA caused small reduction in compressive strength. The reduction was proportional to the ratio of OPC replaced by OSA or OSP. The OSA used in this study was obtained from burning El-lajjun oil shale at 750°C at University of Jordan burner. The chemical composition of the obtained ash and OPC has been determined. The objectives of this study are to study the effect of partial replacement of OPC by OSP and OSA on the compressive strength and setting time of OPC pastes.

MATERIALS AND METHODS

Materials and test specimens preparations: The cement used in this study was Ordinary Portland Cement as a binder material in concrete mixes. Oil shale was obtained from El-lajjun deposit in Jordan, crushed (by a crusher machine in the laboratory of civil engineering department in Al Zaytoonah University) and sieved to a nominal size between 1.2 and 2.4 mm to form a virgin oil shale powder (without burning) while to prepare oil shale ash, firstly the oil shale crushed before combustion. Combustion of oil shale virgin process was performed in civil engineering laboratory by brick kiln at the University of Jordan. The kiln has a maximum temperature of 1300°C. Therefore, during oil shale combustion the kiln was controlled at a temperature of 800°C. As a result of combustion about 0.5 kg of OSA is produced per kg oil shale with specific density of 1.7 g cm^3. After combustion OSA was grind to the same fineness of cement (about 12% sieve residue over 75 μ). The sand used in the experiments is natural sand. It is natural standard sand, consisting of rounded particles and has silica content not <90%. The sand particle size distribution was within the limits defined according to the British standard and the water used was tap water. Mortar cubes with the above mixtures as binder were made and their compressive strength has been determined at ages of 2, 7, 14 and 28 days. Mortar cubes made using pure OPC as binder to be considered as reference samples. Each mortar mix had made from 1200 g of standard sand and 400 g of binder (cement and OSA or OSP) as shown in Table 1 and 2. A total number of twenty four mortar cube of size 50×50×50 mm as shown in Fig. 1 three cubes from each binder mixture were tested at each age to study the effect of OSA and OSP addition and curing time on compressive strength.

Fig. 1: Mortar moulds (50×50×50 mm)

Fig. 2: Compressive testing machine

Table 1: Composition of mortars containing different proportions of OSA

Batch number	Cement (g)	OSA (g)	of OSA binder (%)	Sand (g)
1	400	0.00	0	1200
2	360	40	10	1200
3	320	80	20	1200
4	280	120	30	1200

The mortar was mixed for 4 min in a laboratory mixer. The weight ratios of (water: binder: sand) were (0.5:1:3), for all samples. The compressive strength of the mortar cubes was measured using compressive testing machine that shown in Fig. 2, the recorded value is the average of three values for each age.

Table 2: Composition of mortars containing different proportions of OSA

Batch number	Cement (g)	OSA (g)	Of OSA binder (%)	Sand (g)
1	400	0.00	0	1200
2	360	40	10	1200
3	320	80	20	1200
4	280	120	30	1200

Fig. 3: Vicat apparatus

Before determining the setting time of binders, the normal consistency for each binder paste was determined. Twelve binder paste samples of size 50×50×50 mm (three samples from each mixture) were tested for setting time using vicat apparatus, shown in Fig. 3.

RESULTS AND DISCUSSION

A chemical analysis of OSA and OSP was performed as bysome previous researches that used X-RAY-XRF type ARL 9800 XP at Jordan Cement Factory. The chemical composition of OPC, OSP and OSA is shown in Table 3. It includes the main chemical compounds of cement (CaO, SiO_2, Al_2O_3 and Fe_2O_3). Moreover, the concentration of the majority of these compounds lies within the optimum ranges recommended for OPC.

The similarity of chemical compositions of both OSA and OSP make partial replacement of cement is highly feasible. However, the concentration of some chemical constituents such as SO_3 and phosphorous in OSA and OSP are higher than the allowed amount. This might have adverse effect on some binder properties. The particle size distribution of the standard sand is shown in Table 4 and Fig. 4. Partial replacement of cement by different ratios of OSA and OSP are shown in Table 1 and 2.

Partial replacement affected the compressive strength of mortar that can be established by comparing the measured values of strength for a given curing time and ratio of OSA and/or OSP in binder as shown in Table 5 and Fig. 5 show compressive strength as a function of curing time and percentage of OSA and/or OSP in binder.

Table 3: Chemical composition of OSP, OSA and ordinary portland cement

Components	SiO_2	Al_2O_3	Fe_2O_3	Ca O	MgO	SO_3	K_2O	Na_2O
OPC	18.94	5.37	3.18	63.65	2.59	2.88	0.82	0.10
OSP	16.20	4.80	2.11	48.50	2.05	3.25	0.65	0.08
OSA	18.60	5.00	1.75	55.24	2.90	3.50	0.56	0.30

Table 4: Particle size distribution of standard sand

Sieve Size (mm)	Passing (%)
0.075	6
0.150	18
0.300	44
0.600	78
1.190	96
2.380	98
4.750	100

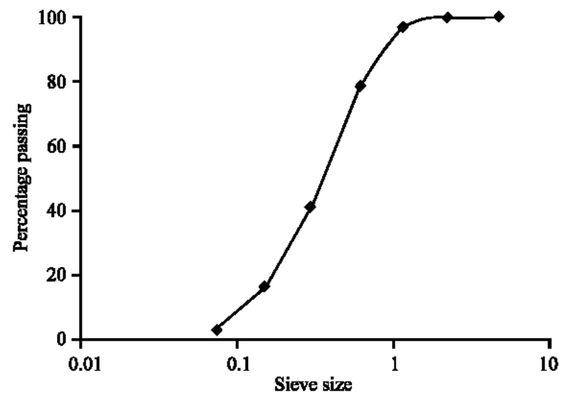

Fig. 4: Particle size distribution of standard sand

It is clearly can be observed that the strength increases with increasing curing time and decreases with increasing OSA and OSP ratios in binder for all mortars. These results comply with the results presented in references (AL-Hasan, 2006). Increase of strength with time is due to the continuous hydration process of cement. Results showed that the compressive strength of mortar cubes containing 10, 20 and 30% OSA decreased by 7.9, 15.8 and 31.6% of reference cement mortar cubes, respectively after 7 days and also decreased by 6.7, 11.1 and 24.4% of reference cement mortar cubes, respectively after 28 days curing compared with strength reference cement mortar cubes. While the strength of mortar cubes containing 10, 20 and 30% OSP decreased by 21.0, 34.2 and 47.4, respectively after 7 days curing compared to the strength of reference cubes and decreased by 15.6, 28.9 and 37.8%, respectively after 28 days curing as shown in Fig. 5. Setting time of cement paste increased by (23-28), (35-38) and (55-60) min when use cement mortar with 10, 20 and 30% OSA and/or OSP comparing with pure cement mortar due to the slow hydration of cement with OSA and/or OSP as in Table 6 and Fig. 6. The reduction in the strength caused by OSA addition decreases as a function of time indicating that strength gaining of mortars

Table 5: Effect of binder OSA and OSP content AND curing time on compressive strength (MPa)

	Time (days)				
OSA or OSP (%)	0	2	7	14	28
0.0	0	24	38	41	45
10					
OSA	0	23	35	38	42
OSP	0	19	30	33	38
20					
OSA	0	21	32	35	40
OSP	0	16	25	27	32
30					
OSA	0	18	26	28	34
OSP	0	12	20	22	28

Table 6: Relation between the setting time and the ratio of OSA and OSP in binder

	Setting time (min)	
OSA or OSP (%)	OSA	OSP
0.0	160	160
10	183	188
20	195	200
30	215	220

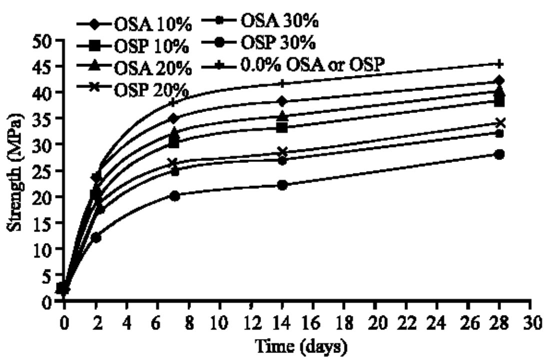

Fig. 5: Effect of binder OSA and OSP content and curing time on compressive strength (Mpa)

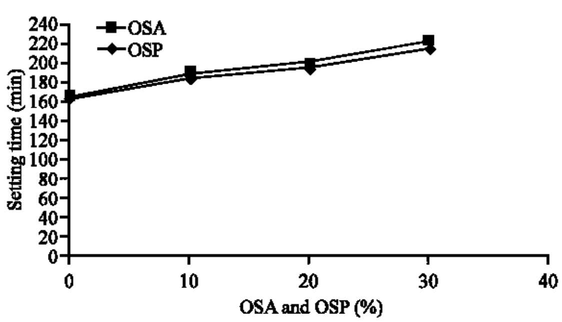

Fig. 6: Relation between the setting time and the ratio of OSA and OSP in binder

pure cement mortar is due to the lower content of ferrous component of OSA and/or OSP in their chemical compositions formulation. Also the more reduction in the strength caused by OSP comparing with OSA addition due to the oil that exists in the voids inside the virgin OSP

Table 7: Relation between OSA or OSP ratio in the binder and the required water content

Batch No.	Cement (g)	OSA (g)	OSA (%)	OSP (g)	OSP (%)	H_2O (mL)	W/C ratio
1	400	0	0	0	0	116	0.29
2	360	40	10	40	10	120	0.30
3	320	80	20	80	20	128	0.32
4	280	120	30	120	30	131	0.33

which makes un-bond around the cement particles during the cement hydration. The results indicated that the strength gaining of mortars containing OSA and/or OSP is slower than that of mortars without OSA and/or OSP. The low development of strength took place due to the increase of SO_3 content which increases by increasing OSA and OSP content. This increase is caused mainly due to the increase of both the required mix water and SO_3 amounts in binders containing OSA and OSP. It is expected that a significant reduction in the difference between the ultimate strength of mortars with and without OSA as well as with will take place.

The high water content can improve the workability of concrete where increase of setting time provides adequate time for transportation of concrete mix before casting. The estimated volume of water required to produce pastes of normal consistency for binders containing OSA and OSP ratios of 10, 20 and 30% increases by 4, 12 and 15 mL, respectively compared with binders containing 0% OSA (pure cement binder) as shown in Table 7. This ituation is related to the rough and pore composition of ash particles and their blain fineness in the process of hydration.

CONCLUSION

From the results of the conducted experiments it is concluded that: The results of the conducted experiment that using OSA with OPC as a binder material in cement mortar show higher values of compression strength than when using virgin OSP with OPC due to the oil that is found in the voids of virgin shale which leads to prevent a full bond between OSP and cement from one side and the natural sand in cement mortar mix in the other side.

The higher is the level of cement replacement by OSA and/or OSP, the lower is the compressive strength. The longer is the curing period, the higher is the increase in compressive strength for oil shale binder (OSA and OSP). Partial replacing cement by OSA and/or OSP, even with small amounts is an effective way to increase setting time. The results of the conducted experiment proved the possibility of reuse oil shale ash as replacement in ratios up to 20% without causing significant effects on the studied properties of cement. Environmental protection and improvement of the economics of oil shale exploitation can be achieved by replacement of OPC by OSA rather than OSP.

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REFERENCES

Al-Hamaiedeh, H., O. Maaitah and S. Mahadin, 2010. Using oil shale ash in concrete binder. EJGE, 15: 601-608.

Al-Hasan, M., 2006. Behavior of concrete made using oil shale ash and cement mixtures. Oil Shale, 23: 135-143.

Alabadan, A., C.F. Njoku and M.O. Yusuf, 2006. The potentials of groundnut shell ash as concrete admixture. Agric. Eng. Intl. CIGR. E. J., 8: 1-8.

Hanni, R., 1996. Energy and valuable material by-product from firing Estonian oil shale. Waste Manage., 16: 97-99.

Kikas, V., J. Rass and J. Hralovich, 1986. Influence of ash content of Kukeriste oil shale on the properties of self-stressing shale ash cement. Proc. Tallinn Polytech. Inst., 618: 9-17.

Mahmud, H.B., E. Majuar, M.F. Zain and N.B.A.A. Hamid, 2005. Strength, durability and shrinkage of high-strength rice husk ash concrete. Spec. Publl. Mater. J., 228: 189-212.

Sengul, O., C. Tasdemir and M.A. Tasdemir, 2005. Mechanical properties and rapid chloride permeability of concrete with ground fly ash. Mater. J., 102: 414-421.

Wuhrer, J., 1950. Oil shale hydraulic cements. Cem. lime Plaster, 3: 45-48.