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Evaluation the Effect of Adding Oil Shale Ash on the Compressive Strength of Concrete

Mousa Gougazeh[1*]

[1] Department of Natural Resources and Chemical Engineering, Tafila Technical University, P.O. Box 179, Tafila 66110, Jordan

* Corresponding author's email: mgougazeh99@gmail.com

ABSTRACT

In the present study, the effect of cementing properties of oil shale ash on the compressive strength of the concrete mixtures produced from oil shale ash, cement, sand, and water was investigated. The used shale ash was produced by direct combustion at 830°C in a laboratory muffle furnace of the El-Lajjun oil shale. Based on the chemical composition of shale ash (OSA), it was concluded that this material consists of a high percentage of CaO which forms the properties of cement materials as well as the contents of SiO_2, Al_2O_3, and Fe_2O_3 form the properties of pozzolanic materials. Oil shale ash (OSA) materials have diverse applications as alternative materials for the construction industry and construction technology to reduce environmental risks and achieve sustainability. The results showed that the pressed specimen with 40 wt.% OSA content, 50 wt.% sand content and 30% MW obtained the highest compressive strength of about 9.1 MPa after 28 days of hardening. The highest value of 28 days compressive strength for a compacted specimen containing 35 wt.% OSA and 35% MW were achieved with 12 MPa at a compaction pressure of between 25 and 30 MPa. High compressive strength values were found to be achieved in the compressed specimens by controlling mixing water. It is also indicated that the compressive strength increases as OSA content in the compressed specimen increases and increases as compaction pressure increases.

Keywords: oil shale ash, compressive strength, compaction pressure, combustion, construction, sustainable.

INTRODUCTION

Jordan has limited energy resources, such as crude oil or natural gas, compared to its neighboring countries. However, oil shale is an important and unused energy source in the country. Oil shales in Jordan are widespread. The main deposits are classified as surface mining (open-pit mining) and they are distributed in central Jordan east of Karak and Tafila (e.g., El-Lajjun, Sultani, Attarat, Jurf Ed Darawiesh, etc.) [1]. The oil shale covers a wide area (>70 billion tons) in Jordan from north to south [2], and it gives a considerable added value to the Jordanian economy by preventing the importation of demand oil, energy, and development of the country.

Several investigations have been conducted into Jordanian shale on the parameters of the operation for the use of oil shale. Most of them concentrated on the organic part of the oil shale for use as an alternative to oil [3–5]. However, there are few works that deal with the utilization of fly ash produced as waste from the different oil shale industries, which represents more than 50% of the total amount of processed raw oil shale. A large amount of ash represents a great environmental concern and one of the most important hindrances which contribute negatively to the utilization of oil shale [6].

The El-Lajjun deposit was selected for this study because it provides good conditions for direct combustion [6]. The El-Lajjun oil shale deposit is one of the most important central Jordan OS deposits (Figure 1), and the proved reserves of the El-Lajjun oil shale deposit are about 1.2 billion tons and covering an area of 24 km^2

[7]. Accordingly, the economic utilization focuses on the use of oil shale ash (OSA) as main material in cement production.

The OSA is a high-calcium ash as detected by XRD. It composed mainly of lime (CaO), anhydrite, calcite, quartz, fluorapatite with traces of clinker mineral phases as C_2S, C_3A and C_4AF) [6]; [8, 9]

The significance of this study lies in promoting sustainable environmental development for oil shale resources through limitation and reduction of the environment deleterious materials from the residues and ash resulting from the combustion or/and direct combustion processes of oil shale materials to produce the thermal and electrical energy. In addition, the present study aims to help the construction industry by providing them an alternative material for cement which is comparable to commercially available cement but at lower production cost and energy which will be sustained the national industry and economy.

EXPERIMENTAL METHODS

Materials

The oil shale representative sample used in this work was collected from the El-Lajjun deposit, central Jordan (Figure 1). The oil shale ash was produced by the burning experiment of the oil shale bulk sample at 830°C in the laboratory. The mineralogical composition of raw oil shale and the combusted oil shale (OSA) was identified by X-ray diffraction (XRD) and is illustrated in Figure 2. The chemical and mineralogical analyses of the original oil shale (OS) sample and the produced oil shale ash (OSA) are presented in Table 1 and Figure 2. As it was shown in Table 1 and Figure 2, the OSA was mainly composed of high calcium oxide with a significant amount of 38.20 wt. % CaO and 8.50 wt. % SO_3. It is clear from the X-ray diffraction analysis (Figure 2) that calcite is the dominant mineral in the raw oil shale followed by quartz, with traces of fluorapatite, whereas at a temperature of 830°C, the obtained OSA consisting mainly of Lime (CaO_{free}), quartz, anhydrite, fluorapatite; and clinker mineral phases such as Gehlenite ($Ca_2Al_2SiO_7$), belite (C_2S), tricalcium aluminate (C_3A), and calcium aluminoferrite (C_4AF). These main crystalline phases are produced by burning at high temperatures kaolins and calcite [6]. As a result, both calcite and lime are present in the obtained OSA. This is due to the crystalline structure of calcium carbonate (calcite) had not been decomposed completely to lime (CaO) [6].

The chemical analysis and physical characteristics of the OSA in the present work were compared with the chemical and physical properties of other well-known deposits (Table 1). Based on the results presented in Table 1, the characteristics of Jordanian OSA were favorable for cement manufacturing due to the significant content of CaO (38.2 wt. %) and thus a smaller content of SO_3 (7.50 wt. %) than that of the other OSAs. Furthermore, the composition of OSA is close to the Estonian oil shale ash [10, 11]. Table 1 shows the physical test values of OSA as conducted in accordance with the CSA A3001 [12]. The total quantity of mixing water should not exceed the target of the mix design by more than 3 percent.

Experimental procedure

In this study, the design of experimental research was conducted in the laboratory in which some of the parameters were fixed while the other parameters were investigated as the subject of the experiment. Three raw mixes were used from oil shale ash, silica sand, and water. The natural silica sand used in this study were provided by the Jordanian Cement Factory. The concrete

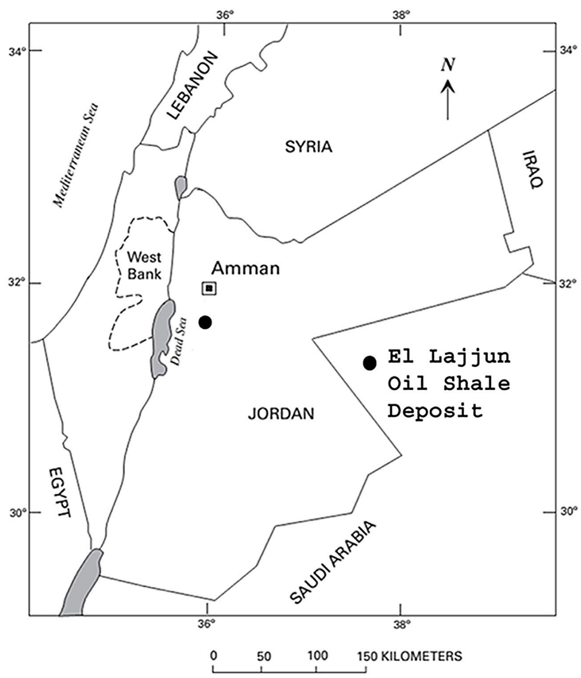

Figure 1. Location of the El-Lajjun oil shale deposit, central Jordan (after [6])

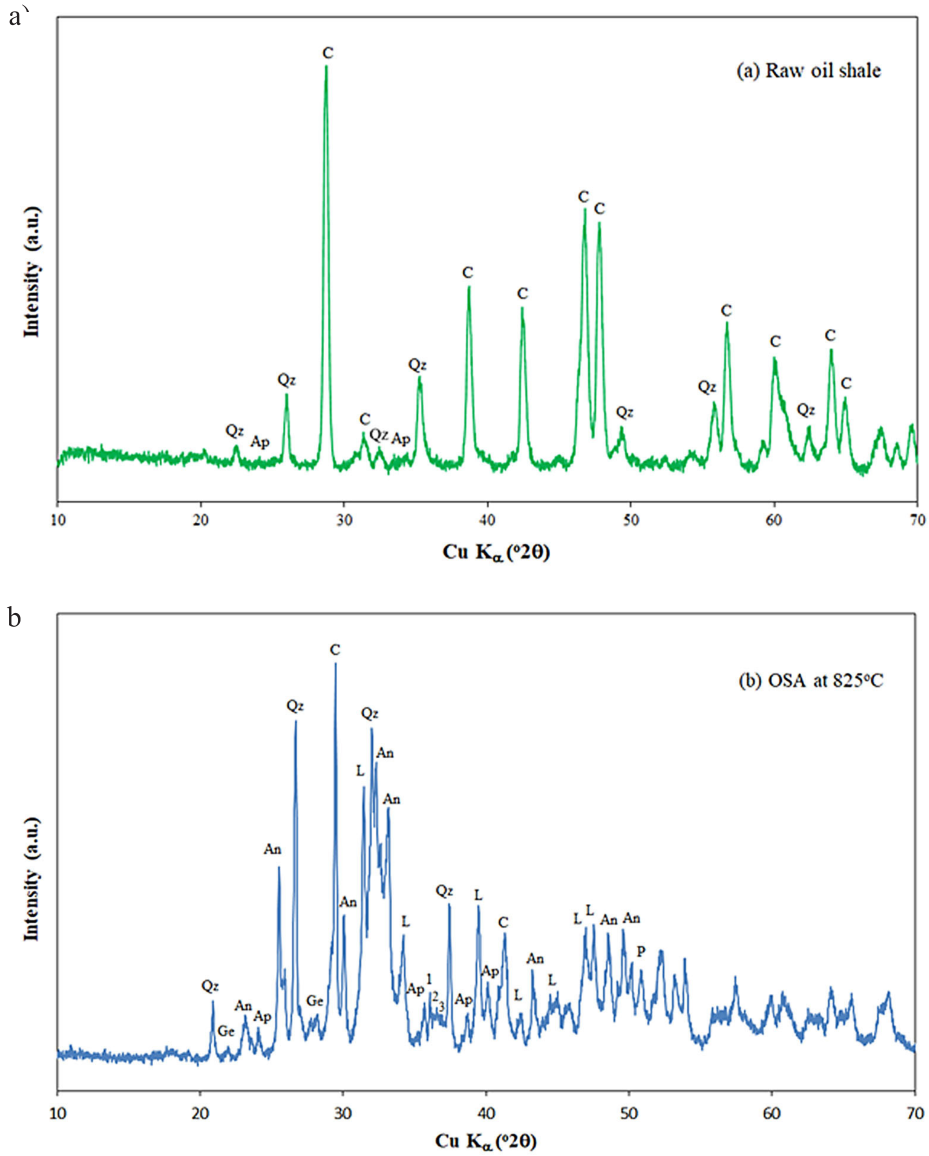

Figure 2. X-ray diffraction pattern of the El-Lajjun (a) raw oil shale and (b) oil shale ash. (C: calcite (CaCO3); Q: quartz (SiO2); L: lime (CaO); An: anhydrite (CaSO4); Ap: fluorapatite; P: portlandite (Ca(OH)2); G: gehlenite (Ca2Al2SiO7); 1: C2S; 2: C4AF; 3: C3A)

Table 1. Comparison of chemical composition of Jordanian oil shale ash with well-known OSA

Occurrences	This study	Estonia [10]	China [13]	Colorado [13]	Germany [13]
Combustion temperature	830 °C	830 °C	860 °C		
SiO_2	26.40	20.79	59.8	32.0	12.0–25.0
Al_2O_3	6.20	5.93	20.50	7.20	9.0–12.0
TiO_2	0.28	0.32			
Fe_2O_3	2.40	3.30	9.9	2.70	6.0–7.0
CaO	38.20	35.76	0.5	21.80	16–60
MgO	2.80	4.23	2.8	7.50	1.4–2.0
SO_3	7.50	7.32	-	-	9.0–10.0
LOI	14.80	16.62	-	20.0	-
$Na_2O + K_2O$	0.70	1.16	2.5	2.30	-
Specific surface area (cm^2/g)	1300	1134	-	-	-
Specific gravity (g/cm^3)	2.52	2.68	-	-	-

specimens in the laboratory were prepared and cast as 45 mm mortar cubes, the specimens were kept and remolded after 24 hours. The compacted specimens were made of mixtures of OSA to silica sand (the used silica sand was ground to 920 cm^2/g). The concrete mixtures were mixed for 5 minutes in a laboratory mixer and then the cubes were cast in wooden moulds, remoulded after 24 h. The specimens were compacted using compacted pressures ranges from 5 to 30 MPa with mixing water content ranges from 10 to 30%. These specimens were hardened at 20°C and then tested at the age of 28 days. 18 cubes of 45×45×45 mm in size of concrete mixes with different mass proportions of OSA, silica sand, and MW contents were designed to measure compressive strength. The compressive strength measurements of the concrete specimens (45 mm cubes) were conducted according to CSA A3001 (Canadian Standards Association). Compressive strength measurements of the concrete specimens (45 mm cubes) were carried out using a universal testing machine (MEGA 2-3000-100 D Seidner and Co. GmbH, Riedlingen, Germany).

The three mixes were designed to investigate the effect of varying contents of OSA, silica sand, and mixing water (MW) on the compressive strength of pressed specimens at different compaction pressure after 28 days of hardening. The first test specimen of concrete mix was prepared from 55 wt. OSA and 45 wt. % silica sand. OSA-silica sand mixes ranged from 10 to 45 wt. % and MW varied from 10 to 35% by weight. The mix made of 65 wt. % of OSA. 35 wt. % sand and 30% MW was prepared as a reference for investigation and evaluating the effect of OSA content on the compressive strength. The contents of silica sand and MW formed the second mix ranged from 20 to 70 wt.% and 10 to 30% by weight, respectively. The second mix is designed to investigate the silica sand content on the compressive strength while changing MW amount. The third mix was prepared to examine the compressive strength of pressed raw materials after 28 days of hardening. The contents of OSA and silica sand formed the third mix composed of 60 wt.% and 40 wt.%, respectively with 30% MW by weight.

The composition of compacted concrete mixes shows the distribution in OSA content, amounts of MW, silica sand content, and compaction pressure on the compressive strength of the pressed specimens on three different mixes. The main variable affecting the compressive strength of the pressed specimens were investigated, oil shale ash contents, mixing water (MW) contents, silica sand contents, and compaction pressure. The proportions of concrete mixes and their mass distribution are given in Table 2.

RESULTS AND DISCUSSION

Compressive strength

The influences of the various contents of OSA, silica sand, and MW on the compressive strength of specimens obtained at different compaction pressures and after 28 days of hardening were investigated and evaluated below.

Effect of oil shale ash content

Figure 3 reflects the effect of oil shale ash content on the compressive strength of concrete mixes with both 20 and 25% amounts of mixing water after 28 days of hardening. As can be seen from Figure 2, the compressive strength curve was close to straight line and exhibited the highest strength (~ 9.1 MPa) of mix containing 40 wt. % OSA, 60 wt.% silica sand, and 30% MW. As shown in Figure 3, compressive strength gradually increased with increased of OSA content for both 25% and 30% MW. Furthermore, the higher value of compressive strength of pressed specimens containing 30% MW than those in specimens containing 25% MW. The maximum value of compressive strength for pressed specimens containing 35 wt.% OSA reaches 7.32 MPa and 8.95 MPa for MW contents of 25% and 30% OSA, respectively (Figure 3). Figure 4 reveals the effect of adding oil shale ash on the compressive

Table 2. Material mass distribution of concrete mixes

Components	Mix distribution					
Oil shale ash (OSA wt.%)	10	20	25	30	40	45
Mixing water (MW%)	10	15	20	25	30	35
Silica sand (wt.%)	20	30	40	50	60	70
Compaction pressure (MPa)	5	10	15	20	25	30

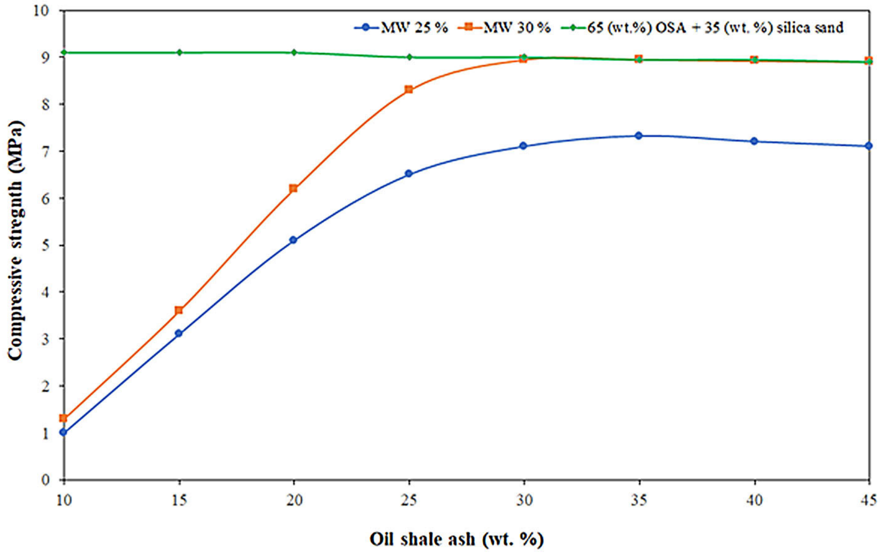

Figure 3. Effect of OSA content on the compressive strength of pressed specimens hardened for 28 days

strength of concrete at 30% MW and after hardening 7 and 28 days. In all specimens, the compressive strength increased with age. It was found that the values of compressive strength of specimens show a dramatic increase at 28 days than those at 7 days of hardening in terms of the effect of adding OSA contents. The mechanical characteristics of ashes obtained from oil shale of the El-Lujjun deposit are in agreement with the results obtained in previous studies [14–16].

Effect of mixing water content

The effect of mixing water content on the compressive strength of pressed specimens is plotted in Figure 5. Figure 5 indicated a dramatic increase in compressive strength as the MW contents increased from 10% to 35% for both specimens with 25 wt.% and 35 wt.% OSA. It was found that the compressive strength values revealed a dramatic increase with an increase in the amount of mixing water. On the other hand, it was stated that the optimal amount of mixing water depends on the content of SO_3 in OSA based binders. High water content can improve the workability of concrete. These results are close with the results obtained in research conducted using Negev-Israel OSA by Freidin et al., 1999 [17]. However, water requirements are determined by the upper and lower limits as specified in CSA A3001.

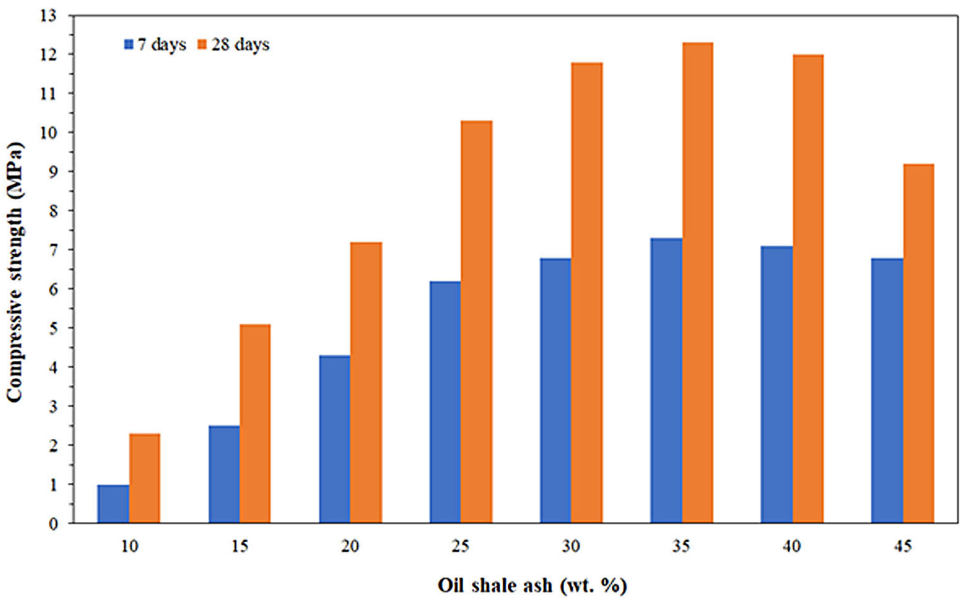

Figure 4. Compressive strength of pressed specimens as a function of OSA after 7 and 28 days of hardening

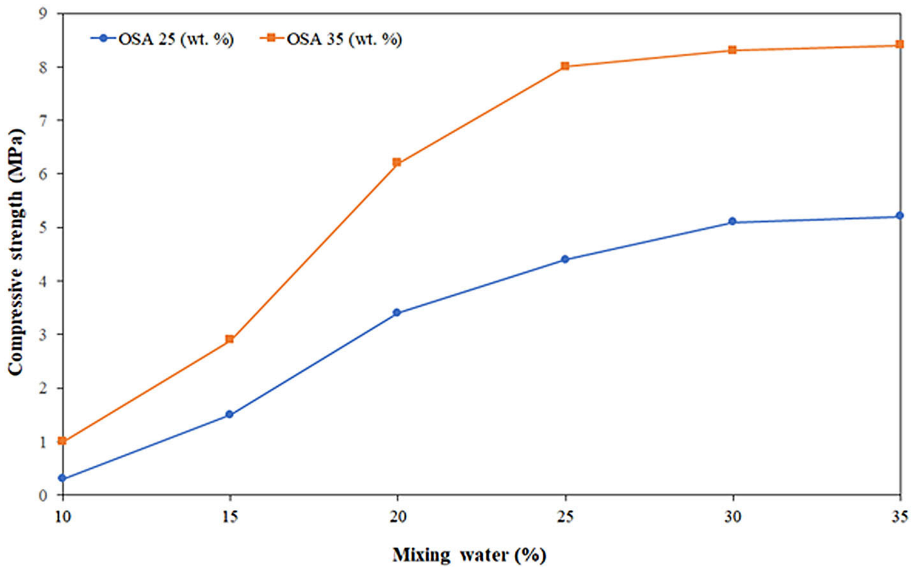

Figure 5. Effect of MW amount on the compressive strength of pressed specimens hardened for 28 days

Effect of silica sand content

Figure 6 shows the influence of silica sand content on the compressive strength of pressed specimens in different amounts of MW. Figure 6 indicates a dramatic increase in sand content as MW increased from 20% to 25% in the pressed specimens. Silica sand content can reach between 20 and 70% whereas MW has increased from 20 to 25%. The silica sand content cannot exceed 50 wt. % at 15% MW.

Compressive strength was found to have gradually increased with silica sand content ranging from 30 to 50 wt.%. On the other hand, the compressive strength showed a dramatic decrease when the silica sand content increased from 50 to 70 wt.%.

Effect of compaction pressure

Figure 7 shows compaction pressure effect on the compressive strength of the pressed specimens. As shown in Figure 6, the compressive strength of specimens has consistently increased from 4 to 8.3 and from 6 to 12 MPa for each of the OSA contents with 25 wt.% and 35 wt.%, respectively when the compaction pressure was increased from 5 to 30 MPa. These results comply with the obtained results of research conducted using China OSA from Wangqing County of Jilin province by Shi et al., 2022 [18].

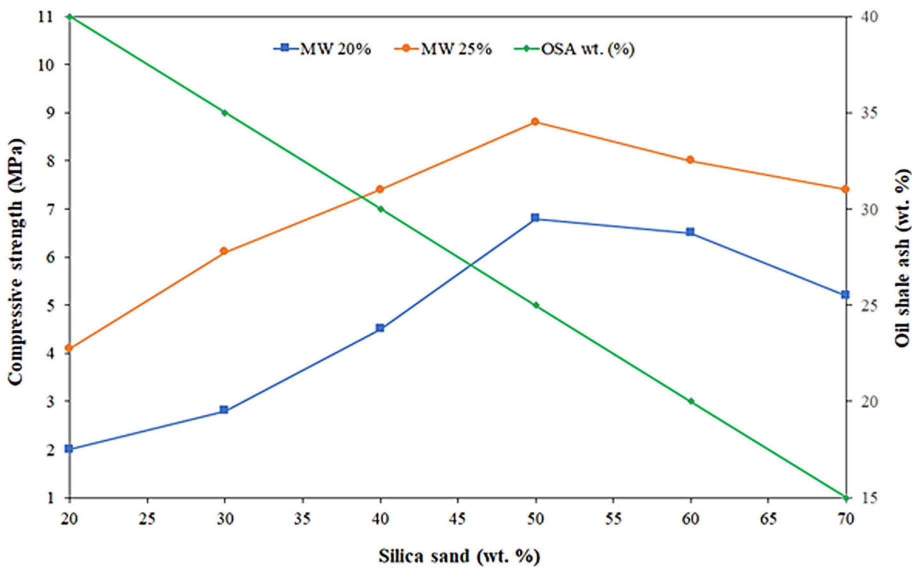

Figure 6. Influence of silica sand content on the compressive strength of pressed specimens cured for 28 days

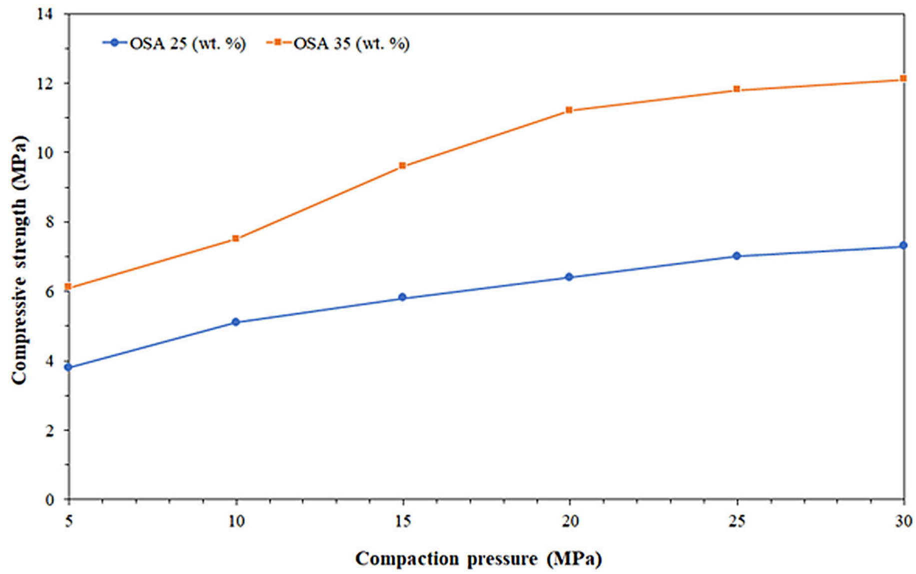

Figure 7. Effect of compaction pressure on the compressive strength of pressed specimens cured for 28 days

CONCLUSION

From the obtained results in the present study, it was concluded some points of great important.

The huge amounts of abundant oil shale ash materials produced by direct combustion operations of oil shale to produce the various kinds of energy have a significant potential supporting of the national economy through the production of sustainable cement and building materials.

The present study investigated the influence of adding of OSA content, silica sand content, amount of mixing water and compaction pressure on the compressive strength of pressed specimens.

The maximum value of compressive strength was measured at about 8.95 MPa at 35 wt.% OSA with 30% MW. However, the compressive strength decreased as OSA content was increased above 35 wt.%, whereas the strength was detected as more than 9 MPa at 65 wt.% and 35 wt.% silica sand mixture.

The value of compressive strength was increased significantly as the content of silica sand increased to 50 by weight and the strength shows a dramatic decrease as the content of silica sand increased by more than 50 wt.%. The compressive strength increased significantly as compaction pressure of the pressed specimens increased.

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