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COMPRESSIVE STRENGTH ANALYSIS ON PROBLEMATIC SOILS STABILIZED WITH FLY ASH IN JORDAN

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Abstract

The paper analyses the compressive strength of problematic soils as marlstone, limestone, and brown clay in Jordan, considering the capacity to use the fly ash residue obtained from the combustion of oil shale as a cement-like material for building works contributing in minimizing the environmental impact of the expected huge output of solid waste resulting from the retort residue of the oil shale rocks. After blending soils collected from Jordan with both fly ash at different percentages (10%, 20%, 30%, 40%), and cement (5%, 10%, 15%, 20%) their compressive strength is compared. Mixtures of problematic Jordanian soils stabilized with 20-30% fly ash fulfil the acceptability conditions to be used as sub-base layers in road building works.

Key words: compressive strength, fly ash, Portland cement, problematic soil, oil shale

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1. Introduction

The current research aims to investigate the compressive strength of some problematic soils stabilized with fly ash in Jordan, considering the ability to use the fly ash as a residual product obtained by direct combustion of either oil shale as a cement-like material for ground stabilization works, especially in the realization of road and embankment building works (Boboc et al., 2010a; Timu et al., 2017). Samples of marlstones, limestones and brown clays collected from Amman area, Jordan are from problematic soils due to their poor strength characteristics and high susceptibility to successive swelling-consolidation behaviour during rainy winters (Abed et al., 2009; Shaqour et al., 2008).

The Jordanian oil shale is available mainly in the central and southern parts of Jordan lands, in El-lajjun district, about 120 km south from Amman City, mostly in the subsurface (Abdelhadi et al. 2012; Alnawafleh and Fraige, 2013). The El-lajjun oil shale deposit, the shallowest known in Jordan with the average thickness ranging between 25-30 meters, was discovered by a joint Jordanian-German geological team in the late 1960s. Since then, the intermittent exploration activity has resulted in 198 drill holes, approximately 1 billion tonnes of oil shale resources (Alali, 2006).

The deposit is accessible and presents favorable mining conditions. Jordan, ranked as the 7th country in the world for its oil shale reserves, possesses over 52 billion tonnes of geological reserves of oil shale spread over 23 known sites of shallow and deep deposits in most of the Jordanian districts, varying in their organic content, thickness, average oil content, and overburden thicknesses (Abed and Arouri, 2006). Among these deposits formed in the Cretaceous age, El-lajjun represents the core for any future investment interest in Jordan (Abdel Hadi et al., 2008).

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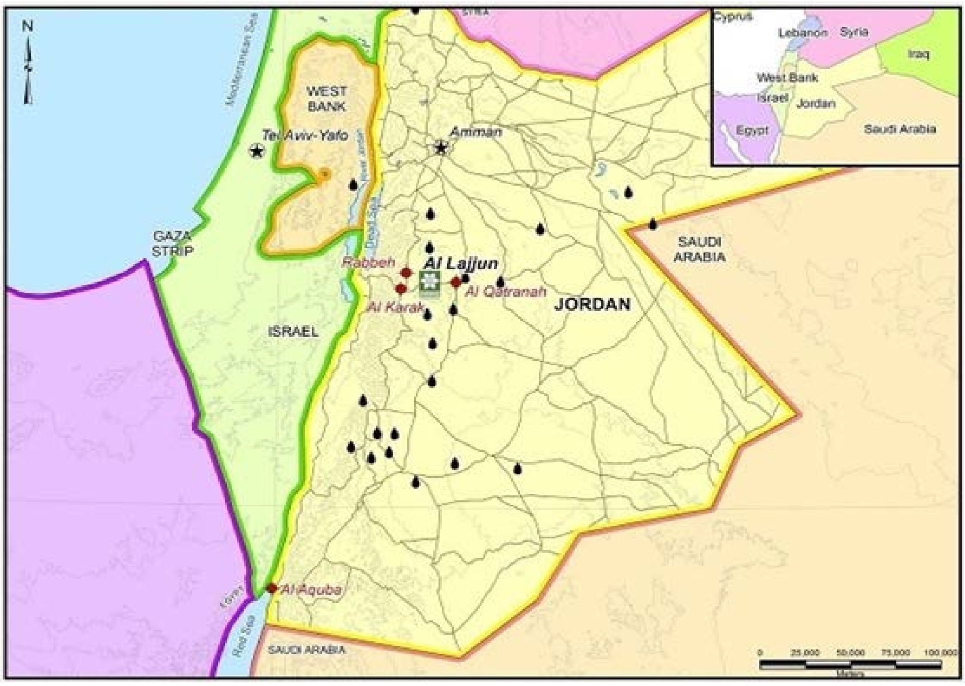


Fig. 1. El-lajjun Oil Shale Deposit in Central Jordan
(according to Survey of Energy Resources, World Energy Counsel, 2007)

Oil shale is one of the most promising alternatives of power sources in Jordan, still one of the essential concern about utilizing it is the environmental impact of its by-product, namely the fly ash produced from their combustion through the retort residue process (Abdelhadi et al., 2011; Harja et al., 2009b). That is the reason why, apart from its commercial advantages, there are significant environmental, technical and sustainability benefits associated with the use of fly ash as a binder in hydraulically bound mixtures consumed in construction works (Bărbuță et al., 2009).

Fly ash usage as a cement reduces the quantity of material sent to landfill, preserves natural aggregate capacity, and reduces the overall greenhouse gas emissions. These are all environmental and sustainability reasons for considering it an important environment-friendly mineral resource for the future (Oros, 2005). The self-hardening properties of fly ashes offer strength advantages over natural clay and granular materials in soil stabilization and hydraulically bound sub-bases due to the small quantity of free lime that they contain (Harja et al., 2009a; Masu et al., 2016; Rotaru and Boboc, 2010a; Singh et al., 2016).

2. Materials and methods

The major concept of this study is mixing marlstone, limestone and brown clay collected from the Jordanian sites with fly ash at different percentages (10%, 20%, 30%, and 40%), and with cement (5%, 10%, 15%, and 20%). A comparison between the compressive strength of fly ash mixtures at the age of 28 days and cement mixtures at the same age was performed in the laboratory (Boboc et al., 2010b; Ciocinta et al., 2010). The fly ash was obtained as a residue from the combustion of the oil shale in the automatically controlled electrical oven. Cement was used for comparative purposes, as both fly ash and cement are considered self-cementing materials, different percentages of cement being replaced by fly ash (Rotaru and Boboc, 2010b; Serbanoiu et al., 2017).

2.1. Materials

2.1.1. Marlstone

Marlstone, a calcareous clay containing more than 40% calcium carbonate with about 10% clay fraction and a considerable amount of silt, spreads over a considerable area in Northern Jordan where Amman City is located, marl deposits covering most of the West and North area of the city. These deposits serve as foundations for roads and many buildings, as well as a fill material for structural backfillings, particularly for road bases and sub-bases (Shaqour et al., 2008). It is yellow in colour, it swells when absorbs water and, in fact, it is prone to cause small-scale landslides. It has a high moisture content and a less dry density, having a low shear resistance. For these reasons, marl is unsuitable as a subgrade material being also-called problematic soil.

2.1.2. Limestone

Limestone is a sedimentary rock composed of at least 50% calcium carbonate ($CaCO_3$) in the form of calcite mineral. Limestone is spread over a large area in Jordan, being mainly used as a façade cladding material and the main source of aggregates. The weathering process converted much of this limestone into a soil that is mainly used for landfills and as a subgrade for highways. It is composed of more than 60% calcite ($CaCO_3$) and its particular geo-engineering difficulty consists in the loss of strength. Aside from erosion, the dissolution of limestone is always the main concern, especially in wet seasons.

2.1.3. Brown clay

Brown clays are typically formed over long periods of time by the gradual chemical weathering of rocks. The formation of brown clay deposits is classified into residual deposits and transported deposits. Residual deposits are formed in place and settled in place. On the other hand, transported deposits are usually formed as a result of a secondary sedimentary deposition process after they had been eroded and transported from their original formation location. Compared to residual deposits, transported deposits usually exist in thicker layers.

The Western part of Amman City is composed of large areas of silty-sandy brown clay which extend in most cases to several meters in depth. This clay belongs to the Smectite group, which is known for its high swelling and shrinkage potential during the wet and dry seasons. Many buildings and roads in the Western part of Amman are subjected to differential settlements and cracking which cause a lot of structural issues. Furthermore, this soil is called brown clay in Jordan even though it does not contain more than 30-35% of clay fraction. Tests have been conducted on the brown clay collected from Khalda district, Amman.

2.1.4. Fly ash

Fly ash is a by-product of the oil shale combustion clearly dependent on the original composition of the parent bituminous oil shale and the temperature of combustion, which has cement-like properties (Magharbeha et al., 2012). The chemical composition of the fly ash samples resulted from the combustion of the oil shale in the oven at 950ºC for 5 hours is compared with the Portland cement (Table 1) to reveal the ash potential as a self-cementing material recommended in stabilizing problematic soils.

Each problematic soil has been mixed with substitutive material as follows:

- ***Case 1.*** Marlstone from Jordan mixed with: Cement (5%, 10%, 15%, and 20 %); Fly ash (10%, 20%, 30%, and 40 %).
- ***Case 2.*** Limestone from Jordan mixed with: Cement (5%, 10%, 15%, and 20 %); Fly ash (10%, 20%, 30%, and 40 %).
- ***Case 3.*** Brown clay from Jordan mixed with: Cement (5%, 10%, 15%, and 20 %); Fly ash (10%, 20%, 30%, and 40 %).

2.2. Sample preparation

2.2.1. Procedure for preparation of soil-cement samples

This step includes the following operations:

1. At the beginning, the grain size distribution for each type of soil, i.e. marlstone, limestone and brown clay was determined.
2. After finding the soil grain size distribution, soils was oven dried at 105ºC for 24 hours, then placed into the Los Angeles Abrasion Machine to be crushed at the required number of 500-600 revolutions depending on the soil type.
3. Soils have been sieved after the crushing process, then samples passing sieve#40 and retained on sieve#100 were chosen for mixing and testing.
4. Adequate amounts of dry samples were weighted.
5. For the four case of mixtures (with 5%, 10%, 15%, 20% cement), the cement added to each sample was weighted.
6. The empty ban was cleaned, dried and then weighted.
7. Both materials, i.e. soil and cement, were mixed in the ban (Fig. 2c).
8. The amount of water needed to reach the optimum moisture content (OMC) was weighted.
9. The amount of water needed for the cement hydration was calculated as 0.5 of the cement weight, i.e. w/c = 0.5, then it was weighted.
10. The total amount of water requested for reaching the OMC and w/c was poured into the mixture and then mixed.
11. The (5x5x5 cm) mould was cleaned and lubricated to prevent sticking (Fig. 2a).
12. The sample was compacted in a single layer to fully fill the mould.
13. Each mould was filled with a fixed amount of soil and water related to its maximum unit weight and its optimum moisture content (OMC).
14. Three cube samples were made for each type of mixture, i.e. 4 x 3 cubes.
15. Cubes were left to harden for 28 days.

2.2.2. Preparation procedure for soil-fly ash samples

This step includes the following operations:

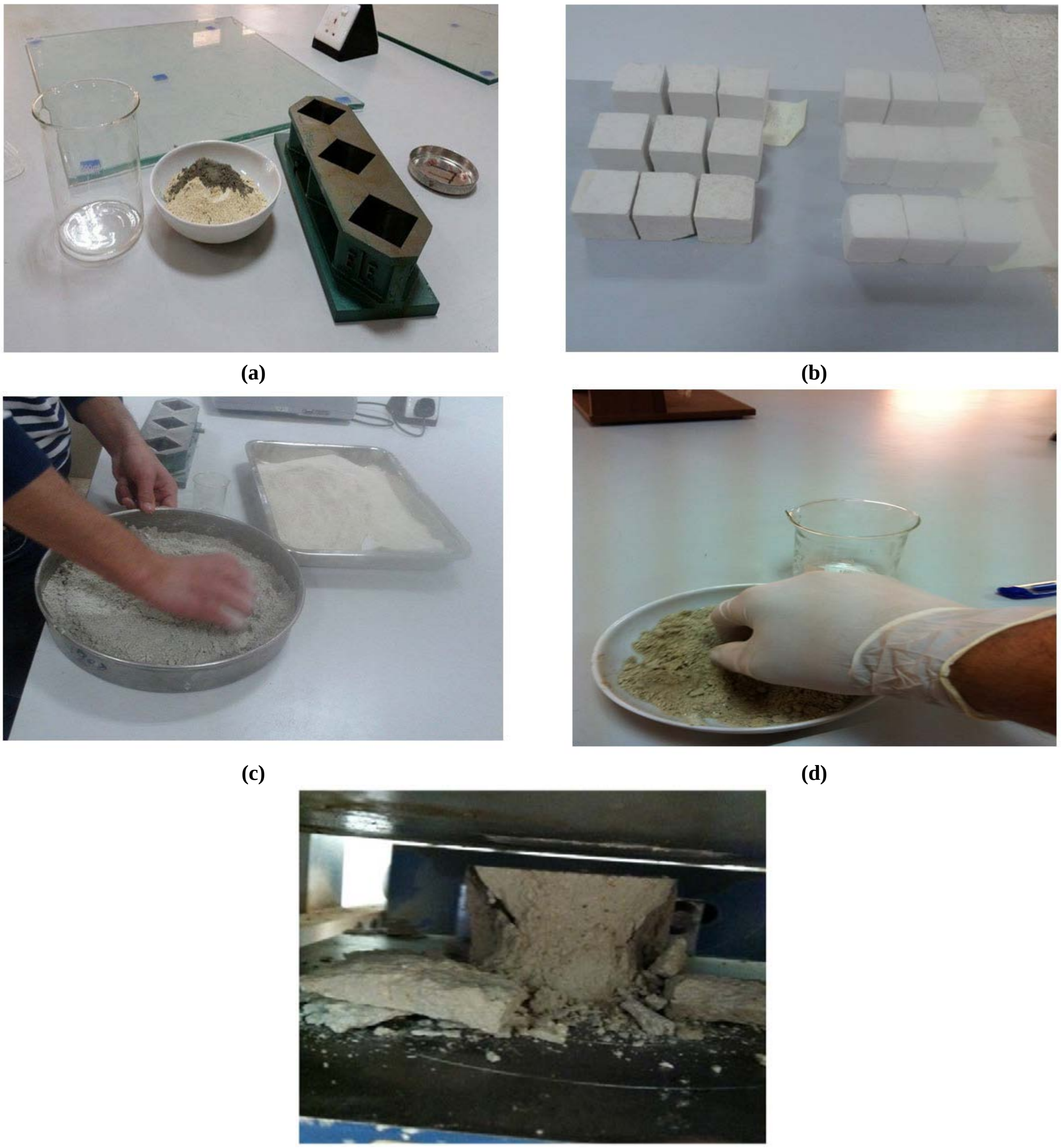
1. At the beginning, the grain size distribution for each type of soil was determined.
2. The oil shale was combusted in the oven at 950ºC for 5 hours, then crushed and sieved and the resulted fly ash passed through the sieve#100 and retained on the sieve#200.
3. Adequate amounts of dry samples were weighted.
4. For the four cases of mixed soil (with 10%, 20%, 30%, 40% fly ash) and for each type of soil, i.e. marlstone, limestone and brown clay, the ash added to the sample was weighted.

Table 1. Chemical composition of the fly ash samples comparative with Portland cement

Material [%]	***SiO_2***	***Al_2O_3***	***Fe_2O_3***	***CaO***	***MgO***	***PO***	***NaO_2***	***TiO_2***	***MnO***
Fly ash	25.80	2.47	1.49	46.02	1.75	5.82	0.96	0.23	0.02
Portland cement	23	4	2	64	2	-	-	-	-

5. The empty ban was cleaned, dried and weighted.
6. Both materials, the soil and fly ash, for each type of soil, were mixed in the pan (Fig. 2d).
7. The amount of water needed to reach the optimum moisture content (OMC) was weighted.
8. Water was poured into the mixture until it became homogeneous.
9. The (5 x 5 x 5 cm) mould was cleaned and lubricated to prevent sticking.
10. The mixture was compacted in a single layer to fully fill the mould.
11. Each mould was filled with a fixed amount of soil and water depending on its maximum unit weight and optimum moisture content (OMC).
12. Three cube samples were made for each **3.** type of mixture, i.e. 4 x 3 cubes (Fig. 2b).
13. Cubes were left to harden for 28 days.

The test was conducted on the basis of ASTM-D3080-98. To minimize the errors by taking the average value, three samples prepared for each percentage of cement and fly ash for each of the three types of Jordanian soils, namely marlstone, limestone, and brown clay were left to harden for 28 days at indoor temperature. Then, each sample was crushed using the concrete compression testing machine. The device was set up to crush a sample of 5 x 5 x 5 cm and the strain factor was removed (Fig. 2e), readings being taken due to stress only, and not envisaging strain aspects.



(a) (b) (c) (d) (e)

Fig. 2. Preparation of soil-fly ash samples: (a) steel mould; (b) marlstone with fly ash cubes; (c) mixing cement with limestone; (d) mixing fly ash with limestone; (e) failure of samples under compression

3. Results and discussion

After mixing the given Jordanian soils: marlstone, limestone, brown clay with cement under different percentages (5%, 10%, 15%, and 20%), the variation of the compressive strength is illustrated in Fig. 3 for all studied materials.

Mixing soils collected from Jordan: marlstone, limestone, brown clay with fly ash under different percentages (10%, 20%, 30%, and 40%) provides the development of compressive strength (El-Hasan et al., 2014) %); the variation of the compressive strength is illustrated in Fig. 4 for all tested materials.

Figs. 5(a-c) compares the values of the compressive strength that marlstone or limestone or brown clay collected from Amman, Jordan develops at the age of 28 days when stabilized with cement / fly ash, respectively (Abdelhadi and Gotoh, 1997). The results vary in values depending on the type and quantity of additives, but the compressive strength values for soil-cement mixtures are always higher than those developed by soil-fly ash mixtures (Abdelhadi, 2013).

As it is shown in Fig. 3, mixing initially marlstone with cement 5% - 10% increases the compressive strength of marlstone rapidly, then it remains constant between 10% and 15% cement to gradually increase as the cement percent increases from 15% to 20%. Mixing limestone with cement increases the compressive strength of limestone initially in a constant level from 5% to 10 % cement. Then, the compressive strength development sharply increases as the cement percentage increases from 10% to 20% (Fig. 3). Also, mixing brown clay with cement increases the compressive strength of clay; initially, the compressive strength increases rapidly from 5% to 10 % cement.Then, between 10% and 15% cement, the compressive strength development is low to gradually increase as the cement percent increases from 15% to 20% (Fig 3).

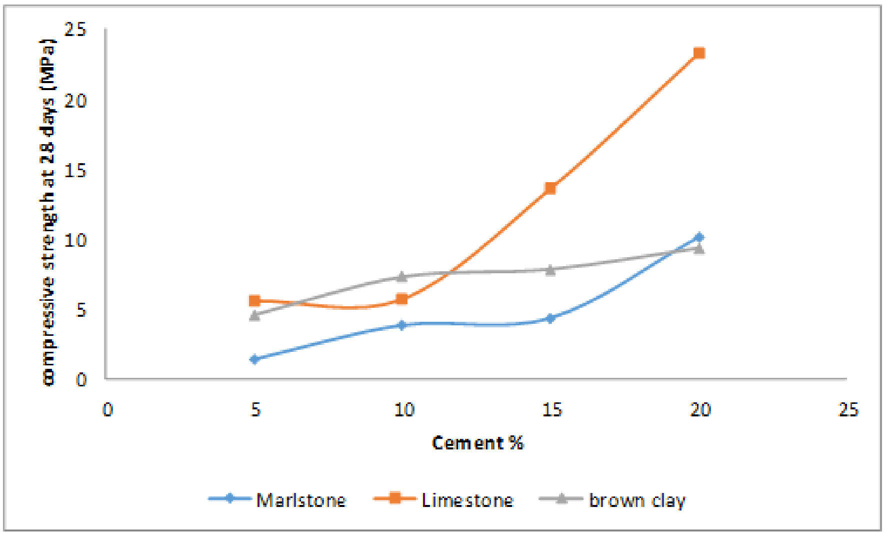


Fig. 3. Compressive strength results for soil-cement mixtures at 28 days for all studied materials

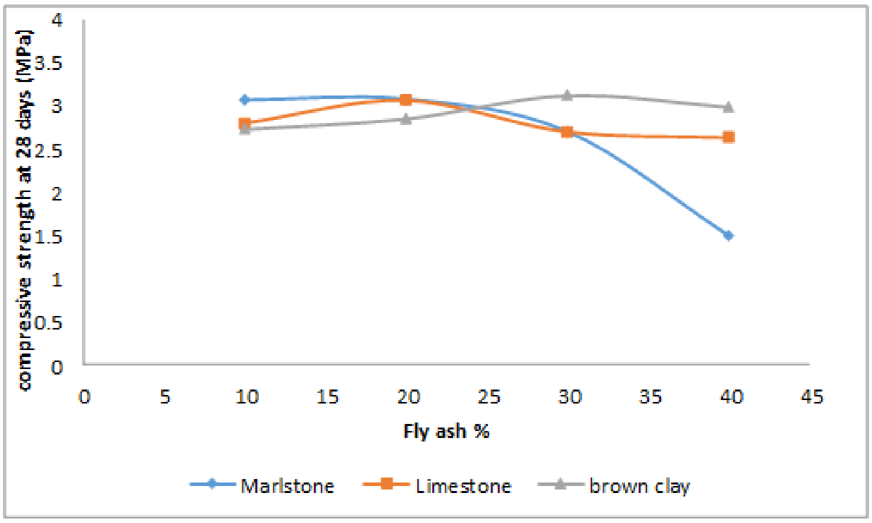


Fig. 4. Compressive strength results for soil-fly ash mixtures at 28 days for all studied materials

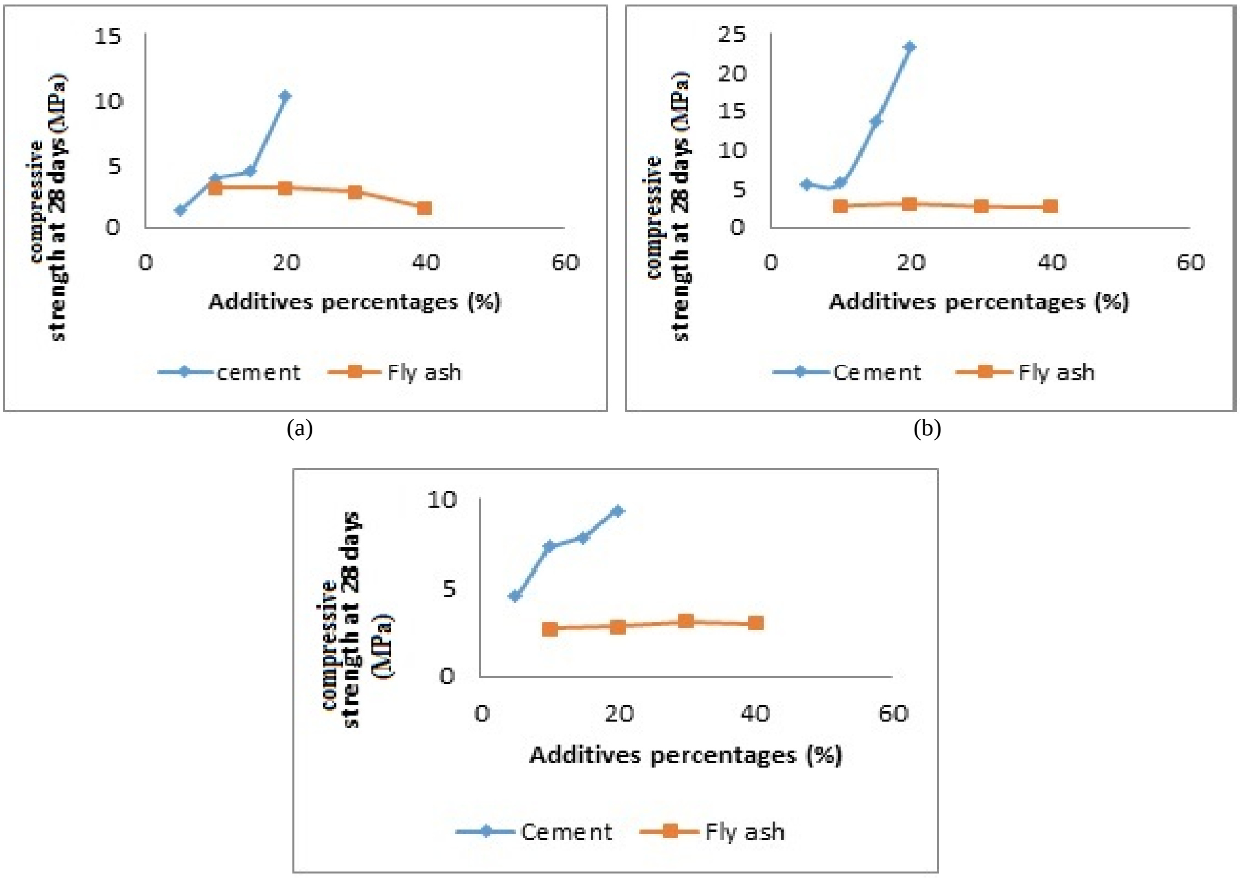


Fig. 5. Comparative values of compressive strength for mixtures of different soils with cement and fly ash: (a) marlstone; (b) limestone; (c) brown clay

When mixing limestone with cement as an additive material provides the highest compressive strength value, a high development (Fig. 3). Mixing brown clay with cement provides an intermediate compressive strength value, i.e. an intermediate development compared with limestone and marlstone. Mixing marlstone with cement provides low compressive strength values, i.e. a low development compared to brown clay and limestone.

By mixing marlstone with fly ash decreases the compressive strength of clay. Initially, the compressive strength slowly increases from 10% to 20% fly ash content. Then, the compressive strength development gradually decreases as the fly ash percent increases, giving low compressive strength values (a low development) (Fig. 4). When mixing limestone with fly ash, the compressive strength of limestone rapidly increases from a 10% to 20% percentage of fly ash, giving intermediate compressive strength values (an intermediate development) compared to marlstone and clay. Then, the compressive strength decreases sharply as the fly ash percentage increases. At 30 % fly ash, the compressive strength stays stationary, yet below the initial level of the limestone-cement mixture (Fig. 4). By mixing brown clay with fly ash, the compressive strength of brown clay increases. Initially, the compressive strength increases rapidly from 10% to 30% fly ash, giving the higher compressive strength values (a high development). Then, the compressive strength decreases sharply but still above the initial level, as the fly ash percent increases (Fig. 4).

Comparing the values of the compressive strength developed at the age of 28 days for soils as the marlstone, limestone or brown clay collected from Amman, Jordan stabilized with cement / fly ash, respectively, the results vary in values depending on the type of soil and quantity of fly ash, as Fig. 5 shows, yet the values developed by the soil-cement mixtures are definitely higher than those developed by the soil-fly ash mixtures. A percentage of 20 – 30% fly ash added to any type of tested soil develops the optimum ratio compressive strength / soil mixture.

4. Conclusions

The current construction industry uses a huge quantity of modern building materials to satisfy resistant and safety as well as environment-friendly requirements. Experimental results confirm the possibility of using the fly ash waste in road building works as a cement-like compound of stabilized mixtures of soils like marlstone, limestone, and brown clay as sub-base layers without compromising the structural integrity of the work. Even though the compressive strength of soil-cement mixtures has been found to be higher than that of soil-fly ash mixtures, the use of the fly ash as a cement-like material in road building works is recommendable particularly because it contributes to minimizing the environmental impact of the expected huge output of solid waste resulted from the retort residue of the oil shale rocks or coal combustion inside thermal power plants equally improving the compressive strength of the binder.

The results vary in values depending on the type of soil and the percentage of fly ash. The best results have been obtained on problematic soils stabilized with 30% fly ash, which allows the utilization of the stabilized material as a sub-base layer in road building works.

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