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Technical Note

Experimental Investigation of the Effective Parameters on the Strength of Soil - Cement

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ABSTRACT: Soil-cement is a mixture of Portland cement, soil and water, which are bonded together due to the cement hydration and compaction. It have durability, low permeability and resistance against wear. Water to cement ratio, cement content and type have been commonly investigated as the most effective factors on the compressive strength of soil-cement. This study aims at the investigation of the effects of some other factors, such as Sand Equivalent (SE), Plasticity Index (PI), and gradation of the soil on the compressive and flexural strength of soil-cement. Results show that the compressive and flexural strength of soil-cement increases with increasing the sand equivalent and decreasing the plasticity index of the soil.

Keywords: Compressive Strength, Flexural Strength, Sand Equivalent, Soil-Cement.

INTRODUCTION

Concrete can be defined as a mixture of aggregates (gravel and sand), cement paste, including cement and water, which can be formed in different shapes. The concrete mixtures with unusual properties or produced in unusual ways are called special concrete. Soil-cement is a type of special concrete. The main applications of soil-cement are in the base layer in flexible and rigid pavements, protection of slopes in earth dams and embankments, as sealant in sewage systems and foundation of structures. The main applications of soil-cement are in the base layer in flexible and rigid pavements, protection of slopes in earth dams and embankments, as sealant in sewage systems and foundation of structures (Baghini et al., 2014; Kawamura and Kasai, 2011; Penev and Kawamura, 1992; Tajdini et al., 2017; Tongwei et al., 2014)

According to the definition of ACI 116R, soil-cement is a mixture of soil and a specified amount of cement and water, which is compacted to a high density. The International Committee of Large Dams (ICOLD) defines the soil-cement as a mixture

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of Portland cement soil and water, which due to the hydration and compaction, are bonded together and produce a durable compacted composition with low permeability and wear resistance. A more comprehensive definition of soil-cement is presented by ACI 230IR as: a hard material with specific engineering properties, which is made by mixing of soil, aggregate, cement, possible chemical additives and cement complements, and water, compaction and curing (Ajorloo et al., 2012; Bahar et al.. 2004; Reddy and Gupta, 2005; Sariosseiri and Muhunthan, 2009; Xing et al., 2009)

Soil-cement is used against the Roller-Compacted Concrete (RCC) in projects. Both the soil-cement and RCC are compacted mixture of cement, water and aggregates; however, the main difference is in the type and size of the aggregate particles. The soil used for soil-cement is generally natural fines, while the aggregates used in RCC contain particles larger than 19 mm. The difference in application is that, the soil-cement is commonly used for protection of earth dam slopes, whereas the RCC, is usually used in massive sections such as gravity dams. All types of soils, except, the organic soils, plastic clays and reactive sands, can be used in soil-cement. The most economical soils for this application are those containing 5 to 35% of fines passing sieve No. 200. The soils containing more than 2% of organic materials are strictly prohibited to be used in soil-cement (Amini and Hamidi, 2014; Caberlon et al., 2009; Reddy et al., 2008, Sukontasukkul and Jamsawang, 2012; Sukontasukkul et al., 2012; Tajdini et al., 2014, Taherkhani and and Arshadi, 2018; Yoon and Abu-Farsakh, 2009)

APPARATUS, MATERIALS AND TESTING METHOD

Materials

The materials used in this research include soil, cement and water. In order to investigate the effect of gradation, seven different gradations of soil, conforming to the specifications of the soil-cement and barrow materials of Bakhtiari's dam field were used in this research (Suzuki et al., 2014; Tajdini et al., 2018; Wangs and Bao-fei, 2008). The gradations were selected such as the percentage retained on the sieve No. 4 of all gradations was 15% and the passing percentage of sieve No. 200 ranges from 5 to 35%, with an interval of 5%. Therefore, the sand content of the gradations varies accordingly. The minimum and maximum dry density of the soils were determined according to the ASTM 4254-91 and ASTM D4253-93, respectively. Figure 1 shows the gradations of the soil and Table 1 shows the properties of the soils used in this research. The cement used in this research was the cement type 2 produced by the Tehran factory according to ASTM C 150. Conforming to the specifications of the International Committee of Large Dams, all the specimens in this research were made with the same cement type and content of 9% by the weight of dry soil. In order to prevent the occurrence of inferior reactions with cement, drinking water without the acidic or basic properties was used for making the specimens. The same w/c ratio of 0.8 was used in all specimens. In order to investigate the effect of plasticity index, for three of the seven gradations, the fraction finer than 0.075 mm (sieve No. 200) was used a stone powder with the plasticity index of almost zero and natural clay of field with kaolinite minerals.

Apparatus

The compressive and flexural strength of the mixtures were evaluated by conducting unconfined compressive strength and flexural strength tests on the specimens according to standard methods of ASTM D1634 and ASTM D1635, respectively. The compressive strength tests were conducted in stress control mode, in which, a constantly increasing load was applied on the specimen until the specimen failure, and the flexural strength tests were conducted in strain control mode, in which, the load is applied on the specimen such that the deflection of the beam increases at a constant rate. The compressive strength test set up consisted of two jaws, which the top jaw is moveable and the lower jaw is fixed, and digital system for adjusting the loading rate. The flexural tests were conducted by applying two concentrated loads by two loading rams on the specimens, inducing compression on top and tension at the bottom of the specimen and were continued to the specimen failure.

Preparation of Specimens

The mix design of the soil-cement mixtures was done according to ASTM D2901 and conforming to the Portland Cement Association recommendations. As mentioned earlier, the same w/c ratio of 0.8 was used for all the mixtures. The constituents of the mixture were mixed together using a laboratory mixer. In order to prepare the specimens, required amount of cement was mixed thoroughly achieving a uniform colour and after that water added to matrix and specimens were prepared by compacting this mixture in the mould in three layers with 75 blows. Cylindrical specimens with the diameter of 71 mm and 142 mm in height (H/D=2) were fabricated for the unconfined compressive strength tests and the specimens were cured by placing them in a vapour room for 12 hours, and were tested immediately after curing.

Prismatic 76×76×290 mm beam specimens were used for the flexural strength tests. The specimens were made by placing them in a metal mould with lubricated surfaces in three different layers and compacting by 90 uniform and scattered impacts on the surface of each layer using a hammer until achieving the thickness of 76 mm. After fabrication, the specimens were cured in the same way as used for the cylindrical specimens, and tested immediately after curing. It is worthy to note that the specimens were loading across the sides in contact with the mould.

Finally the compressive tests were conducted by applying the load at a constant rate of 140 kpa/s on the cylindrical specimens, and the flexural tests were conducted by applying the load at two points on the beam at a rate of 0.001 mm/s until the failure of specimen. In this test, the beam is divided into three regions, with the middle section under a constant pure bending moment.

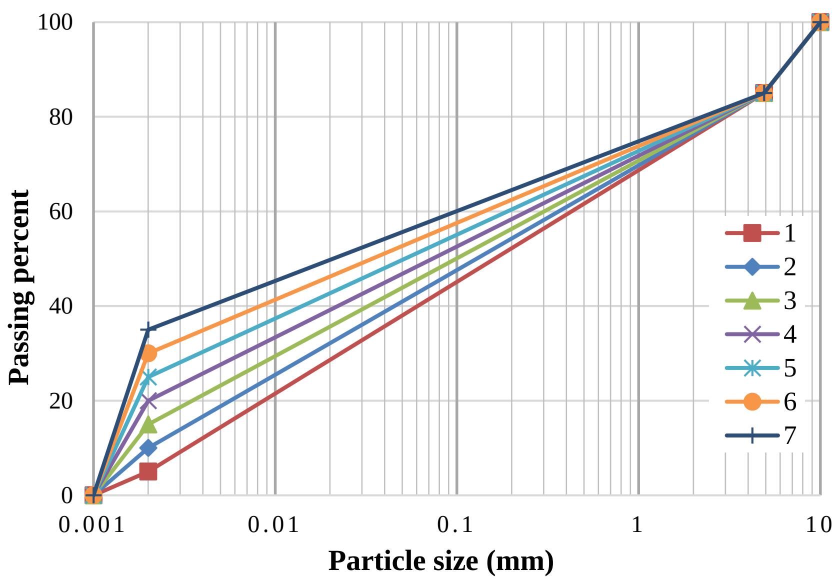


Fig. 1. Gradation curve of different samples from Bakhtiari’s dam borrow pit

Table 1. Physical parameters for the tested soils

Material	γd max (gr/cm^3)	γd min (gr/cm^3)	Cu	Cc	Unified soil classification system	Fine content (%)
Round sand 1	2.02	1.87	120	17	SP	5
Round sand 2	1.97	1.75	175	24	SP-SC	10
Round sand 3	1.88	1.70	164	25	SC	15
Round sand 4	1.82	1.66	167	18	SC	20
Round sand 5	1.78	1.63	128	16	SC	25
Round sand 6	1.69	1.57	107	11	SC	30
Round sand 7	1.64	1.56	84	15	SC	35

UNCONFINED COMPRESSIVE STRENGTH TESTS RESULTS

Unconfined Compressive Strength of Mixtures with Different Gradations

Figure 2 shows the plot of compressive strength (q_u) of the soil-cement mixtures against the curing time. Due to the rounded surface of the soil particles, the maximum and minimum density, as given in Table 1, are the main influential factors on the compressive strength.

It can also be seen in Figure 1 that, Consistent with the results of previous studies (Baghini et al., 2014; Bahar et al., 2004; Caberlon et al., 2009), the compressive strength increases with increasing the curing time, with a higher increase for the mixture with higher dry density, which is attributed to the higher interlock of aggregate particles in a mixture with higher density.

The Compressive Strength of the Mixtures with Different Plasticity Indexes

Plasticity index is determined by obtaining the Liquid Limit (LL) and Plastic Limit (PL) of the soils. Liquid limit is defined as the moisture content level of a soil at which the soil change from plastic state to liquid state. The plastic limit of a soil is the moisture content level at which, the soil begins to behave as a plastic material.

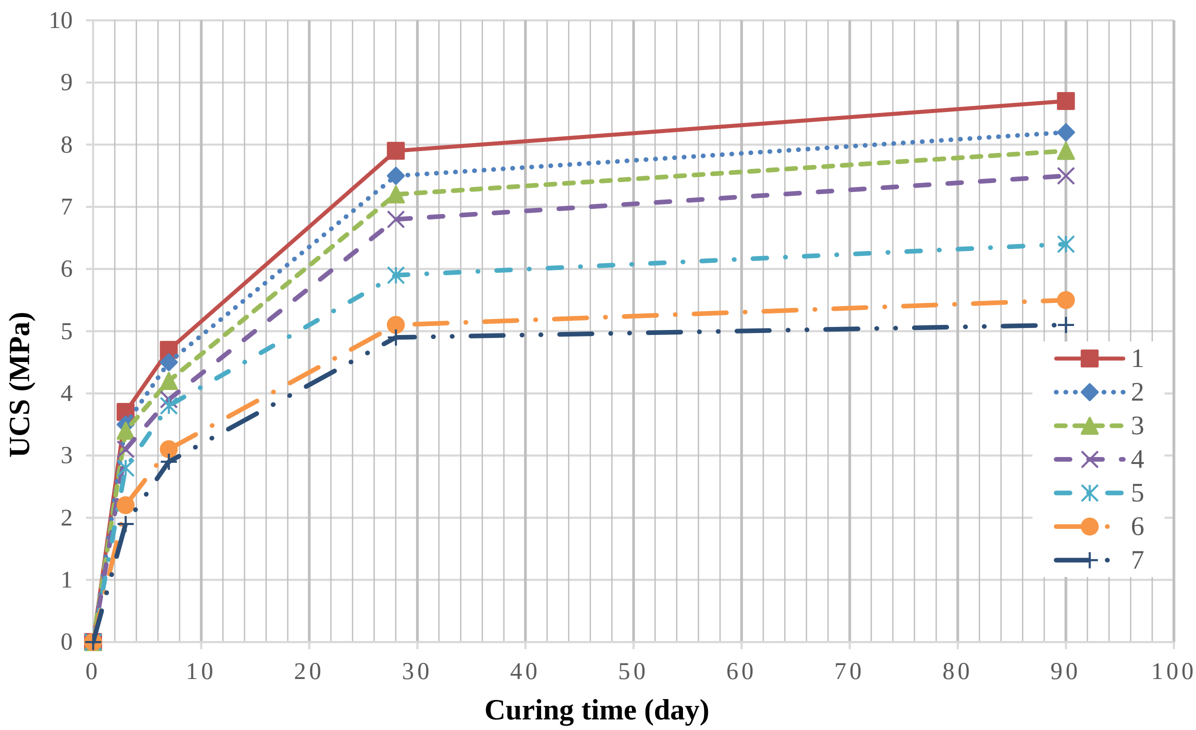


Fig. 2. The compressive strength of the mixtures with different gradations

The plasticity index of the three lower, median and upper extreme gradations (samples 1, 4 and 7), were determined to be 19, 12 and 7%, respectively. Theses gradations were also used with non-plastic stone powder fines. As can be seen in Figure 3, the mixtures with plastic fines have noticeably lower compressive strength, which is may be due to the hydration of water by plastic minerals of clay. Because of applying a constant water to cement ratio in his study, the reduction of strength is even more intensive. It is worthy to mention higher water content is required to be used in mix design of soils with higher plasticity index.

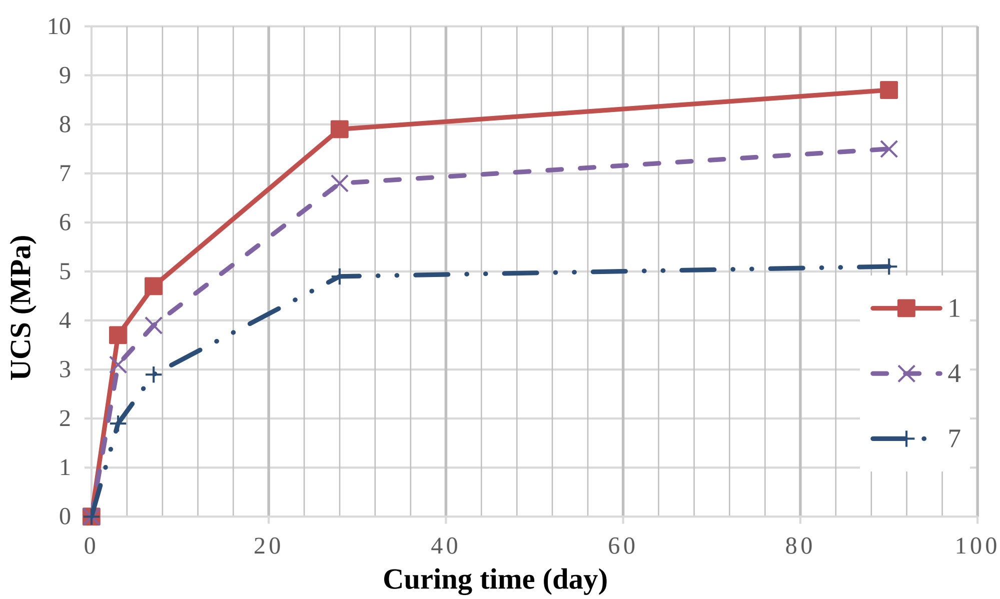
Unconfined Compressive Strength of the Materials with Different Sand Equivalent Values

Sand Equivalent (SE) test is conducted to determine the amount of undesirable colloidal and clay particles in a soil sample and to determine what fraction of the soil is composed of sand particles. The minimum SE of fine aggregates in asphalt and cement concrete, base and sub-base layer in pavement is required by specifications. According to ASTM D2419 standard method, the sand equivalent test was conducted on the samples of soils with the three gradations of lower extreme, median and upper extreme and different plastic and non-plastic fines. Table 2 shows the results of sand equivalent test.

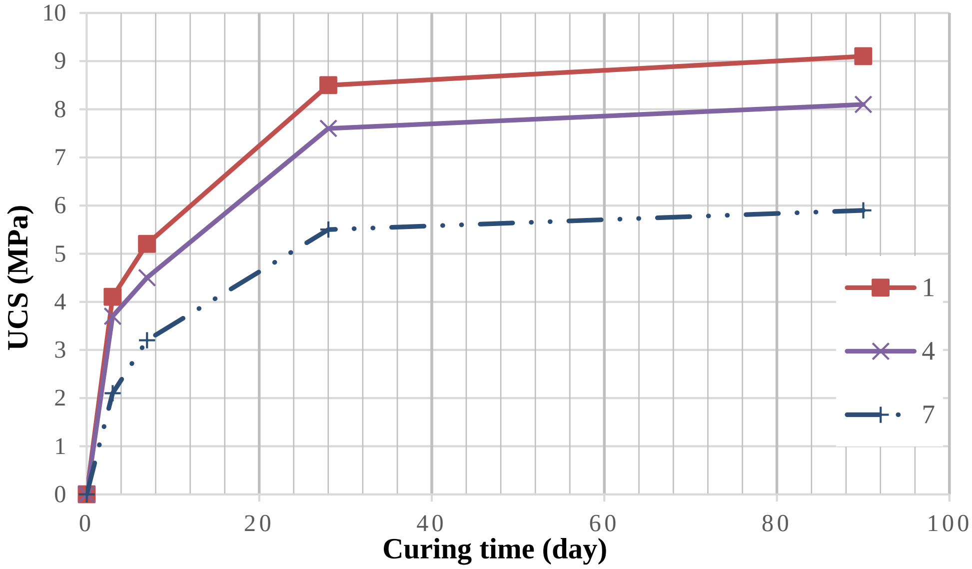
Figure 4 shows the plot of the 28-day compressive strength of the soil-cement mixtures made of the soils with different gradations and plastic and non-plastic fines. As can be seen, the soils with plastic fines have a lower sand equivalent, which result in the reduction of soil-cement compressive strength. This is attributed to the increases of the undesirable particles in fines with decreasing the sand equivalent which adversely affect the compressive strength.

Table 2. Sand equivalent test results on different gradations

Gradation	Sand equivalent with plastic fine content (%)	Sand equivalent with non-plastic fine content (%)
Upper	44	58
Middle	39	50
Lower	31	42



(a)



(b)

Fig. 3. The compressive strength of soil-cement with: (a) plastic and (b) non-plastic fines

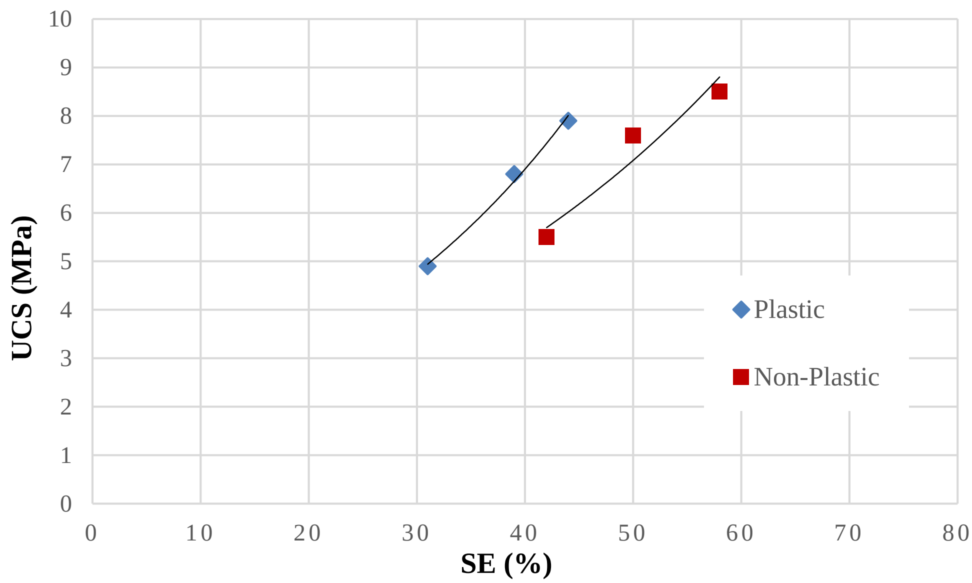


Fig. 4. The compressive strength of soil-cement against the sand equivalent of the soil

FLEXURAL STRENGTH TESTS RESULTS

Flexural Strength of Soil-Cements with Different Gradations

The soil-cement mixtures made of the gradations shown in Figure 1 were undergone a pure bending and the failure criteria was defined as the time at which the cracks develop at the bottom of the beam due to tensile stresses and the bending bearing capacity is no longer increased.

Figure 5 shows the flexural strength of the mixtures made with different gradations. As can be seen in this figure, consistent with the previous studies (Tajdini et al., 2017; Suzuki et al., 2014) the flexural strength is significantly lower than the compressive strength, which is due to the weakness of the brittle soil-cement material in tension.

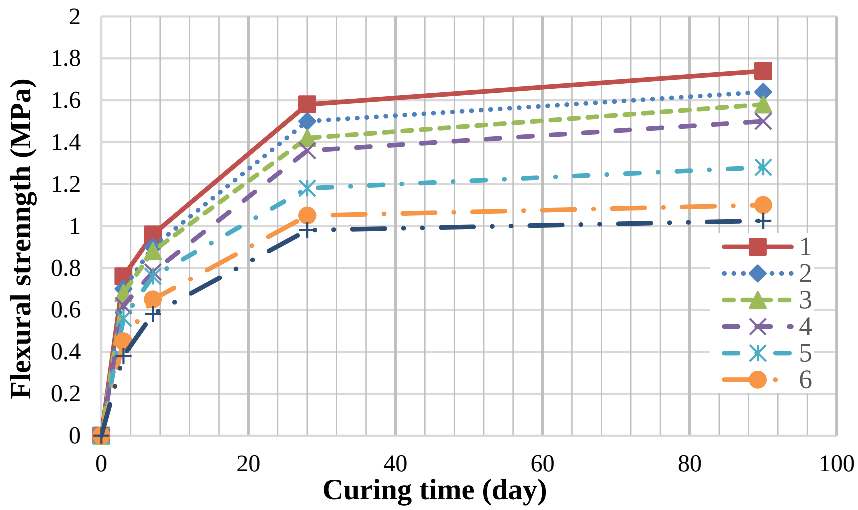


Fig. 5. The flexural strength tests results for different gradations

Similar to the compressive strength, the gradations with higher dry density have resulted in a higher flexural strength than those with lower dry density. The higher density are corresponding to the soils with higher coarse particles content, which their inclusion in the mixture requires higher energy for failure. The path of crack propagation is through the cement binder around the particles, and the length of path for joining the cracks increases with increasing the aggregate size.

Figure 6 shows the laboratory tests and samples for compressive and flexural strength.

Flexural Strength Tests Results for the Materials with Different Plasticity Index

The flexural strength tests were conducted on the soil-cement specimens of 6 different mixtures. Three of the mixtures were made of the soils with three different gradations of lower extreme, median and upper extreme and plastic fines, and the rest with similar gradations and non-plastic fines (stone powder).

(a)

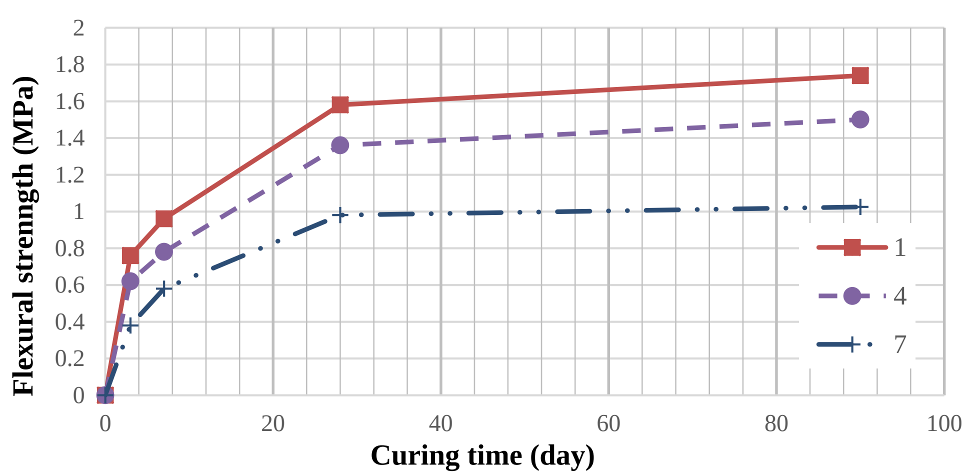
(b)

Fig. 6. Laboratory samples and tests: a) compressive test, b) flexural

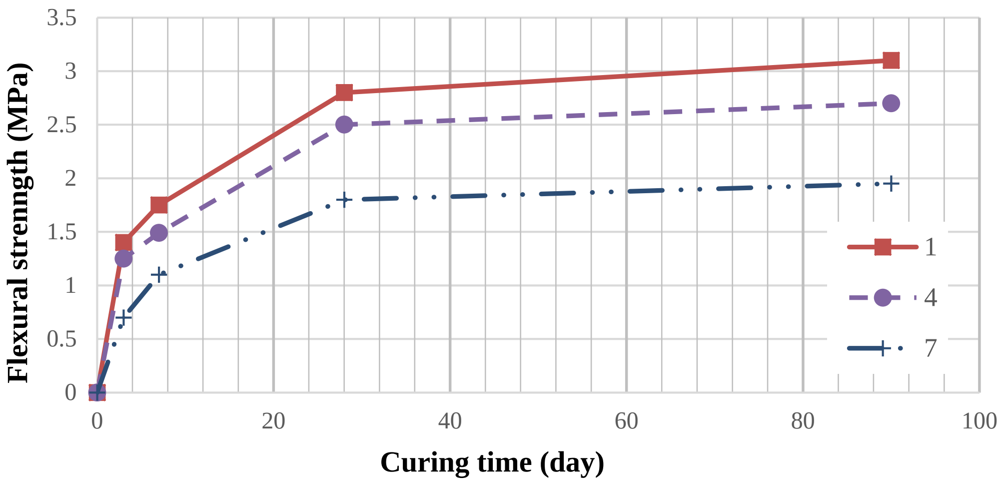
Figure 7 shows the plot of flexural strength against the curing time for the mixtures containing plastic and non-plastic fines. As can be seen, compared with the compressive strength of the same mixtures, as shown in Figure 3, there is a significant difference between the flexural and compressive strength, with a higher difference for the mixture with plastic fines. The flexural strength of the mixtures with plastic and non-plastic fines is approximately 1/5 and 1/3 of the compressive strength of the same mixtures, respectively, indicating that the plasticity index of the fines plays a vital role in the strength of soil-cement mixture.

Flexural Strength of the Mixtures with Different Sand Equivalents

Figure 8 shows the 28-day flexural strength of the soil-cement mixtures against the sand equivalent for the soils with plastic and non-plastic fines. As can be seen, for both the mixtures with plastic and non-plastic fines, the flexural strength increases with increasing sand equivalent, and power function can be well fitted to the variation of the flexural strength with sand equivalent with a R^2=0.96 and 0.97 for the mixtures containing plastic and non-plastic fines, respectively. The same behaviour is expected for the ages of 3, 7 and 90 days. Sand equivalent represented the amount of coarse aggregates which has a vital role for flexural strength. As can be seen in this figure, with increasing in SE could gain high flexural strength rather than materials with low sand equivalent, exponentially.



(a)



(b)

Fig. 7. Flexural strength behavior of the soil-cement with: a) plastic and; b) non-plastic fines

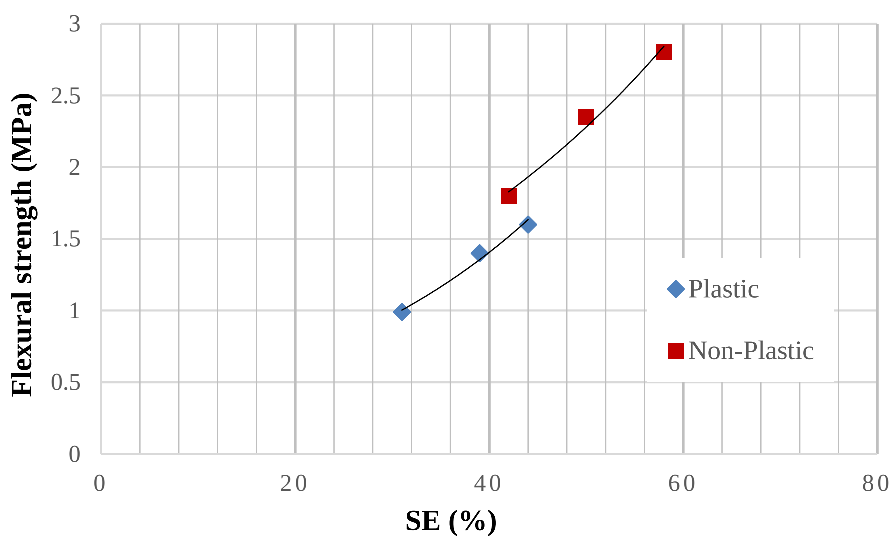


Fig. 8. Variation of the flexural strength with sand equivalent for the mixtures with plastic and non-plastic fines

CONCLUSIONS

- The gradations with higher coarse particles content and higher dry density result in higher compressive and flexural strength.
- The soils with lower plasticity index result in a higher compressive and flexural strength than the soils with higher plasticity index. The compressive and flexural strength of the soil with higher plasticity index are, respectively, 30 and 10% lower than those of the non-plastic soil.
- The compressive and flexural strength of the soil-cement made of the soils with higher sand equivalent are higher than those made of soil-cement made of the soils with lower sand equivalent.
- Results of the flexural and compressive strength tests show that the strength of the soil-cement mixture increases, exponentially, with increasing sand equivalent. The compressive and flexural strength of the soil-cement made of the soil with lower sand equivalent are approximately, 10 and 40%, respectively, lower than those of the soil-cement made of the soil with higher sand equivalent.

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