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Compressive Strength and Permeability of Sand-Cement-Clay Composite and Application for Heavy Metals Stabilization

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Abstract: This study was carried out to test the feasibility of a mixture of sand, cement and clay for their permeability and compressive strength. Various samples with different mass ratios of this mixture were tested to determine their permeability and compressive strength. The best proportions of 25% sand 50% cement and 25% clay show the highest compressive strength and low permeability in comparison with the other proportions. The maximum compressive strength was for the sample that contains 25% sand and 75% cement with a value of 12.83 kN/m^2 obtained after two weeks of curing, while samples that having 25% sand, 25% clay and 50% cement showed also quite good compressive strength with values of 11.05 kN/m^2. This composition showed a permeability value of 9.15x10^{-6} cm/s. The cation exchange capacity was estimated for this mixture to be 53.1 meq/100 g. This composite has a low cost, efficient and durable.

Key words: Permeability, Compressive Strength, Sand, Cement, Clay, Cation Exchange Capacity

INTRODUCTION

Encapsulation of lead ions in sand-cement-clay mixture was performed early, which showed a high ability to return this ion from leaching out into water resources [1]. Transport of this metal is not only controlled by the hardness and compaction of the composite but also by the permeability of these composites toward this heavy metal. Therefore, there is a need to study the effect of microstructure of the stabilized composite material and relates this structure to the seepage of the heavy metals through the composite media. Several research areas were performed on utilizing of different composites for solving some problems related to increasing the shearing resistance, decreasing permeability, increasing soil bearing capacity, decreasing the compressibility and consolidation [2-7]. Others investigated the relation between the porosity and permeability of different composite material. Kearsley and Wainwright studied the effect of replacing large volume of cement with classified and unclassified fly ash on the properties of foamed concrete [8]. They showed that the porosity is mainly dependent on density of the concrete. Chia and Zhang presented an experimental study on the chloride permeability in light weight concrete (LWC) and normal weight concrete (NWC) and found that resistance of LWC to the chloride penetration is similar to that of NWC [9]. Jooss and Reinhardt correlated the relation between permeability of different types of concrete and temperature [10]. Naik *et al.* [11] considered the addition of fly ash onto concrete mixture for chloride penetration. They illustrated that the addition of fly ash can cause a decrease in chloride of concrete up to 50% cement replacement. Tsivilis *et al.* [12] added limestone to Portland cement for the purpose of determination of the nitrogen and water permeability through out concrete. They concluded that the addition of limestone has a positive effect on the water permeability and sorptivity of concrete. Despite the efforts made to decrease the permeability of concrete toward water, gases and anionic species, little study was performed on permeability of heavy metals. This work aims at testing a mixture of certain proportions of sand, cement and clay for permeability of heavy metals. The results will highlight on the optimum weight percentage of sand, cement and clay for encapsulation of heavy metals in contaminated clay soil.

MATERIALS AND METHODS

Clay soil and sand been used in this research brought from Tafila, Jordan, while cement is Type I ordinary Portland (OPC) brought from Jordan cement factory. These materials were crushed, sieved and stored in dry place for further work. The chemicals were analytical grade reagents supplied by Sigma Chemical Company.

Mix Composition: Different weight of sand, cement and clay were mixed in 500 mL beaker according the mass ratios provided in Table 1. The mixing procedure was performed in an isothermal condition using Controls mortar mixer 65-L5 operated at 500 rpm. The water to mixture ratio was varied to maintain constant fluidity to all samples and to reach optimum moisture content. The samples prepared above where divided into two different parts, one is further used in determination of compressive strength while the other is used to obtain the permeability test.

Table 1: Chemical Analysis of Clay and Cement

Component (Wt%)	Clay	Cement
SiO_2	58.86	21.2
Al_2O_3	17.11	5.5
Fe_2O_3	4.20	3.1
CaO	10.85	64.18
MgO	1.66	2.5
SO_3	-	2.63
Na_2O	2.83	0.18
K_2O	2.30	0.71
TiO_2	0.57	-

Compressive Strength: This test involves molding the prepared samples in cylindrical molds (2.5×5.0 cm) and allowed to set for 24 h at room temperature, then transferred into a water container for curing different periods of times (1, 7 and 14 days). The cured samples then hydraulically tested using Controls grade B, C43/C with maximum capacity of 2000 kN. At fixed loading rate until failing occurs. The samples that contained pure soil and clay where tested using the unconfined un-drained shear strength apparatus, Controls E125-3600.

Cation Exchange Capacity (CEC): To test the maximum uptake of the mixed composite toward heavy metals, these composites were further tested according to their exchange capacity toward sodium ions. The method adopted was proposed by Environmental Protection Agency (EPA) according to SW-846 Method 9080 [13]. Each of the composite samples was soaked in sodium acetate solution (1.0 N) for 30 min then rewashed with isopropyl alcohol three times. Then the samples where rewashed with ammonium acetate solution (1.0 N) to exchange all adsorbed sodium ions by the solid samples. The amount of sodium ions desorbed into the solution was tested using SOLAAR S4 Atomic Absorption Spectrophotometer.

Permeability Test Procedure: The permeability procedure is based on falling head method (ASTM D-3434). A representative sample of each composite was placed in a modified Permeameter (2.5×5.0 cm), falling head permeability cell, ELE 25-0605 and the water was allowed to pass through the specimen under constant head condition. The time that is required for certain quantity of water to pass though the samples was recorded. The head difference between the surface of water in the upper tank and the outlet of the Permeameter, h, the quantity of flowing water, Q and water temperature, T, were also recorded.

RESULTS AND DISCUSSION

The chemical composition of clay and cement is shown in Table 1. The analysis to these materials revealed that they contain mainly silica, alumina and calcium oxide, which they account for 89.57% of the total weight. Fifteen samples of concrete were prepared by mixing sand, cement and clay at different compositions. Three different tests were achieved in order to predict the applicability of best composite of sand-cement-clay mixture for encapsulation of heavy metals in aqueous solutions. These test were compressive strength, permeability and cation exchange capacity.

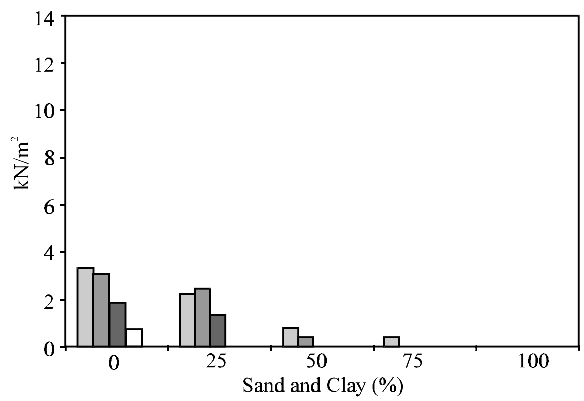

Fig. 1: Compressive Strength for Different Compositions of Sand-clay-cement Mixture Obtained after One Day of Molding

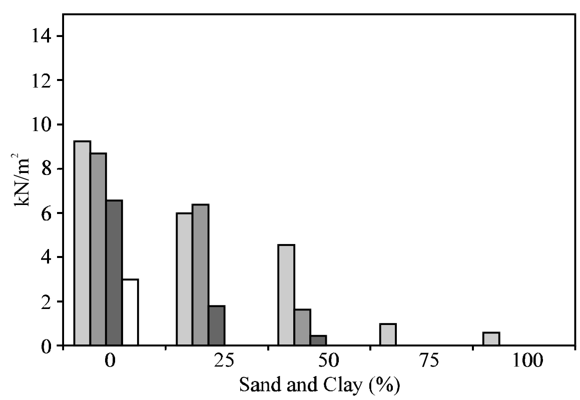

Fig. 2: Compressive Strength for Different Compositions of Sand-clay-cement Mixture Obtained after One Week of Molding

Figure 1 illustrates the effect of different compositions of sand and clay on the compressive strength of the samples. As the percentage of each of sand and clay decreases, the compressive strength will increase. At fixed composition of clay the increase of sand composition will increase the compressive strength. This because of the interaction between sand and cement that yield mortar that provides a higher compressive strength. Figure 2 shows the compressive

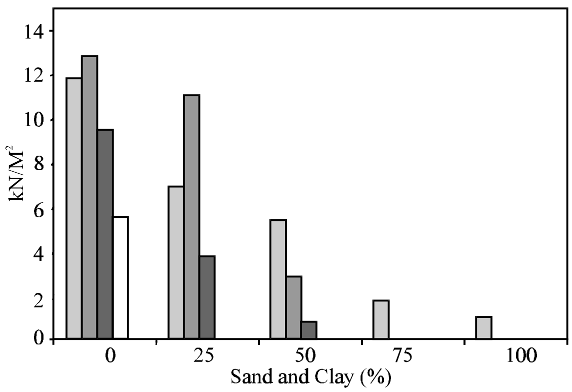

Fig. 3: Compressive Strength for Different Compositions of Sand-clay-cement Mixture Obtained after Three Weeks of Molding

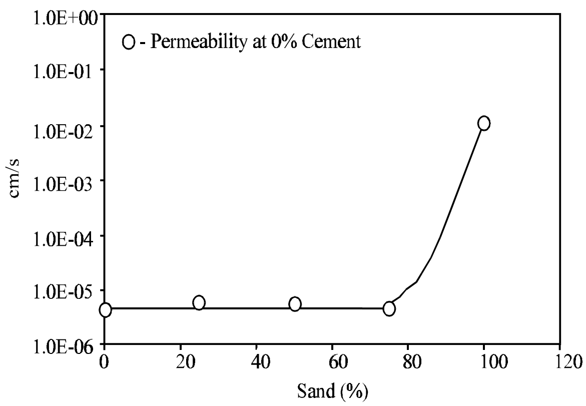

Fig. 4: Effect of Variation of Sand to Clay Ratio on Permeability of the Mixture

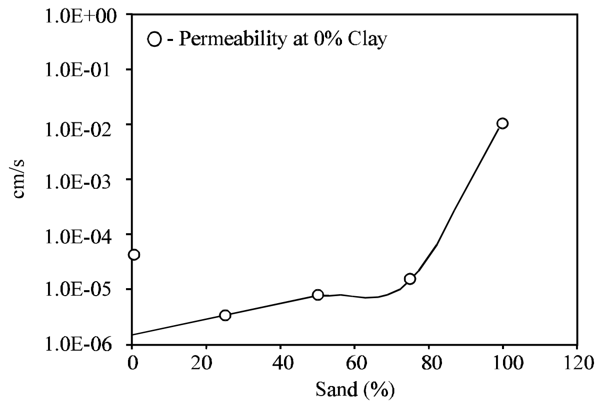

Fig. 5: Effect of Variation of Sand to Cement Ratio on the Permeability of the Mixture

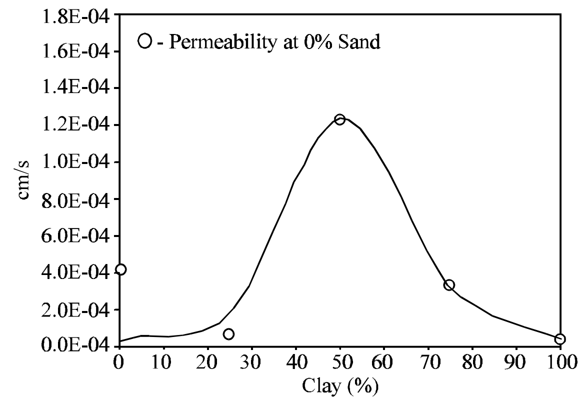

Fig. 6: Effect of Variation of Clay to Cement on the Permeability of the Mixture

strength obtained after one week of molding while Fig. 3 provides values obtained after three weeks of molding. It is cleared that the curing time has a noticeable effect on solidification of the samples. The first one-week of curing provided three orders of magnitude higher in compressive strength that that of one day, while the second week only showed little effect on sample solidification. The increase in curing time allowed an increase in the hydration of the samples which leads in increasing in compressive strength up to 60% of the maximum gained compressive strength within one week, while a gradual increase in this strength was attained thereafter till it becomes constant. After two weeks the rate of gain of strength will decrease and the compressive strength becomes constant. The maximum compressive strength was for the sample that contains 25% sand and 75% cement with a value of 12.83 kN/m^2 obtained after two weeks of curing. Moreover, the samples that containing pure cement or 25% sand, 25% clay and 50% cement showed also quite good compressive strength with values of 11.84 and 11.05 kN/m^2, respectively, while the samples that containing no cement did not show any resistant to compression.

The permeability of composite was also studied at different percentages of sand, cement and clay. The temperature was 20 C to maintain the constant viscosity of water. The coefficient of permeability was obtained using the following formula

$$K = \frac{QL}{Ath}$$

Where K is the coefficient of Permeability in cm/s, L is the specimen height, cm, A is the cross-sectional area of the specimen in cm^2, t is the time required for the water quantity to discharged during test, s and h is the head difference between and lower level, cm.

Figure 4 illustrates the permeability values at different samples that having varied percentages of sand and clay composites. In the absence of cement, as percentage of sand to clay increase, the permeability keeps constant at lower ratios while increases at higher ones. It is cleared that the permeability keeps constant from 0% sand up to 80% with a permeability value of 4.41x10^{-6} cm/s, however at higher value grater than 80% sand the permeability increased exponentially till it reached a value of 1.1x10^{-2} cm/s. Figure 5 shows a gradual increase in permeability with increasing sand to cement

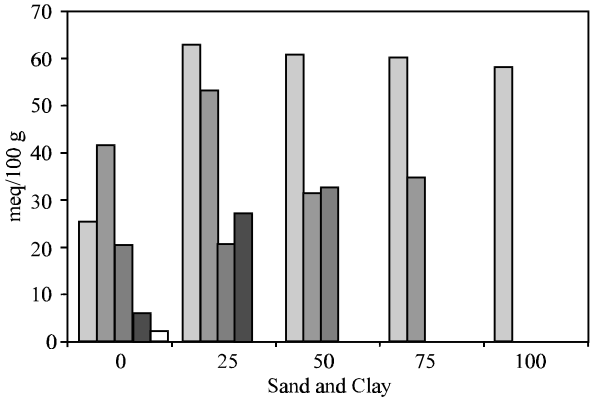

Fig. 7: Cation Exchange Capacity of Samples at Different Clay and Sand Ratios

ratio in the absence of clay. When comparing with Fig. 4, it seems that the interaction between clay and sand yields higher coagulation effect than that of cement with sand (at lower values of sand). Figure 6 illustrates the effect of different compositions of clay and cement on permeability. The highest value was obtained at 50% each, while this value start to diminish when approaching pure case samples. This is attributed to coagulation effect at higher percentages of clay and cement. Similar results were obtained for samples that having 25% sand, 50% cement and 25% clay, 25% sand and 75% cement and pure clay samples with permeability values of $9.15x10^{-6}$, $3.33x10^{-6}$, $4.37x10^{-6}$ cm/s, respectively.

To anticipate the effect of sand-clay-cement mixture in holding and stabilizing heavy metals; the cation exchange capacity test was performed on all samples with different percentages of sand, cement and clay. The CEC provide a clear picture on adsorption capacity of these constituents toward heavy metals. It is cleared that, Fig. 7, as the percentage of cement to sand increases at constant clay composition, the CEC will increase till it reaches a maximum value of 62 meq/100 g for pure cement sample. While 2 meq/100 g was obtained for samples that having pure sands. Similar trend was obvious with the increase of cement to clay ratio at fixed sand composition till it reached a maximum value at 100% cement. This is because that cement is composed of silica, alumina and iron and calcium oxides. These constituents enhance the CEC comparing to that of samples having only pure sand. In addition, the samples that containing 50% clay and 50% cement, 100% clay and 25% clay, 25% sand and 50% cement show pretty good CEC values of 60.86, 57.98, 53.1 meq/100 g, respectively.

CONCLUSION

Mixture of low cost sand, cement and clay was used to encapsulate heavy metals from aqueous solution. Compressive strength and permeability tests, as well as, cation exchange capacity were performed on different mass ratios of these materials. It is concluded that composite containing 25% sand, 50% cement and 25% clay proved to have the best specificity toward permeability, compressive strength and holding heavy metals. The advantage of utilizing this solidification/stabilization mixture is the low cost of its raw material and a relatively the safe treatment of this process.

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