





Research article

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Mechanical and durability properties of stabilized river dredged sediments

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Abstract. Large volumes of sediments are being dredged from the Euphrates River to maintain the stream of the river. These sediments are classified as loose sand with poor engineering properties such as poor grain size distribution, poor compaction, high permeability, and low shear strength. Therefore, these sediments need to be stabilized in order to be utilized as an available and cost-effective engineered fill. In this research, cement by 4, 6, and 8 % was used to improve the strength and durability properties of loose sand sediments dredged from the Euphrates River. Additionally, polypropylene fibers were added by 0.5 % to the cement-treated specimens. A series of laboratory tests were performed to evaluate the unconfined compressive strength and wetting-drying properties of the prepared specimens that were cured to 7 and 28 days. The results showed that adding cement led to improve the compaction process of the cement-treated soil. Furthermore, adding cement by 8 % produced an unconfined compressive strength value as high as 2000 kN/m². Furthermore, when the polypropylene fibers were added, the strength was further increased by 52 %. The results also showed that treatment with cement caused a significant improvement in the resistance to wetting and drying cycles, as the treated specimens passed the test with loss in weight ranging from 16 to 39 % compared to the untreated specimens that collapsed in the first cycle of the test. As discussed herein, the improved sand may provide a valuable source of engineered fill that can be used for many projects such as dams, levees, and road ways.

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1. Introduction

Sediment materials carried by rivers are a crucial part of the erosion and removal of the Earth land surface due to river processes. The movement of material from land to water bodies also has a significant impact on global geochemical cycling [1, 2]. Human activity has significantly affected these natural processes, leading to faster erosion due to changes in land utilization and disruption of the transport of sediment from land to water because of storing vast amounts of material behind dams [3–6]. The movement of sediments from river basins and its transportation by river streams may cause numerous challenges including the reduction of soil resources and the accumulation of sediment in waterways for humanity [7]. The rapid global expansion of international trade and business, as well as the need for deeper navigation channels to accommodate the increasing size of contemporary ships [8]. To preserve or improve their economic competitiveness, ports, harbors, and rivers have to expand the depth of their fairways. Dredging is the process of excavating and extracting silt and rocks from the bed of channels, lagoons, rivers, and other bodies of water with the purpose of increasing the depth and width of these navigation routes. Dredging may also be utilized for the purpose of rehabilitating environmentally affected areas. Dredging is a long-standing method for handling vast amounts of sediments, whereas the quality management of these sediments is a relatively recent concern [9]. The management and control of sediments are now recognized

as crucial environmental concerns for the sustainable use of the available resources [10, 11]. In recent years, the necessity of managing dredging operations and evaluating their economic, social, and environmental impacts caused by polluted sediments has grown significantly in both developing and industrialized nations [12].

According to the directorate of water resources of Al-Anbar Governorate, an estimated volume of 1.5 million cubic meters is being dredged annually from the Euphrates River within the Governorate that costs more than 1.3 billion Iraqi Dinar [13]. As for the engineering aspect, loose sand sediments are usually not suitable for civil engineering constructions because of the poor grain size distribution that cause poor compaction and strength characteristics [12]. Therefore, these sediments need to be stabilized for the purpose of improving the engineering properties by many methods such as adding cement to reduce the high permeability and compressibility and increase cohesion and shear strength for the sediments [14, 15].

Soil stabilization is a controlled technique that improves the soil by incorporating chemicals, allowing it to be used as a foundation or sub-base for roads to withstand the anticipated traffic and pavement stresses [16]. Various techniques are frequently utilized to stabilize soils. There are two approaches to enhance the characteristics of sandy soils [17, 18]. The first technique is mechanical stabilization, which involves mixing the natural soil with a stabilizing material to create a uniform mixture [19]. The second technique is to introduce a stabilizing material into undisturbed soils, allowing it to permeate through the empty spaces in the soil and interact with it [20, 21]. Chemical stabilization involves modifying the qualities of locally accessible soil to enhance its strength and durability. The two most often utilized chemical stabilization procedures are lime and cement stabilization [22]. Portland cement is widely recognized as a material binder for soil stabilization. It is used because it is widely available, easy to use, cheap in price, and has a high bonding ability and various uses. Soil-cement is a mixture of soil, cement, and water that is thoroughly compacted. It is widely used to enhance the soil foundation for dams, dykes, parking areas, and roads on a significant scale. On the other hand, cement-stabilized soils could exhibit notable brittleness property. This can lead to the occurrence of brittle fractures and cracks in subgrade or pavement layers once they are exposed to high lateral earth pressure, seismic loads, or substantial horizontal displacements [23]. When cement is added to the soil, it enters the voids and reduces them, when water is added to mixture, a chemical reaction occurs that causes harden cement, this increasing the density of mixture and reducing permeability.

Soil strengthening involves using natural or synthetic fibers to enhance the mechanical properties, such as strength and load-bearing capacity, of soil. Occasionally, the enhancement of mechanical properties is accomplished by strategically positioning the fibers in key areas within the soil mass [24, 25]. The presence of randomly dispersed fibers in the clay soil leads to enhancements in the flexural toughness, strain in a split test, ductility, and peak compressive strength. The presence of fibers greatly alters the failure process by inhibiting the development of tension fractures. Since the 1970s, researchers have examined the mechanical properties of this type of soil reinforcement by performing relevant studies [26]. Polypropylene fiber (PPF) was a type of synthetic fiber derived from the polymerization of propylene, a linear polymer. There are several benefits to consider, including its lightweight nature, compressive strength, exceptional toughness, and resistance to corrosion [27]. The PPF is commonly utilized with concrete, which is known for its drawbacks such as limited crack resistance, vulnerability to deformation, and relatively low tensile strength [28]. Using of both chemical stabilization and reinforcement with fibers may provide dual advantages by enhancing the mechanical characteristics of soil, such as increased strength and improved ductility. The work of [29] investigated the feasibility of incorporating fibers into cement to enhance the mechanical characteristics of collapsible soil and thereby enhance the behavior of cement-treated soil. A study conducted by [30] used a blend of steel fiber (SF) and cement to improve dredged sediments. The findings demonstrated that augmenting the amount of cement or reducing the amount of water had a substantial positive impact on the compressive strength and exacerbated the fragility of the treated soil.

Improving the engineering properties of sediments will provide a valuable source of engineered fill that can be used for many projects such as dams, levees and road ways. Many previous studies have used cement to stabilize various types of weak and problematic soils. Cement has been proven to be a good stabilizing material. In this research, cement and PPFs were used to improve the strength and durability properties of loose sand sediments dredged from the Euphrates River. Specifically, the unconfined compressive strength and wetting-drying characteristics were evaluated through a laboratory testing program.

2. Materials and Methods

2.1. Materials

The sediment materials were collected from Euphrates River bank in the center of Al-Ramadi city, west of Iraq. This location was considered as significant amount of sediments materials are being dredged on the daily base. The particle size distribution and soil properties are shown in Fig. 1 and Table 1. The chemical tests were conducted according to the British Standards (BS 1990-part3) [31]. The soil is classified as poorly graded sand (SP) according to the Unified Soil Classification System (USCS) per the ASTM D2487-17 [32]. The soil is not suitable as engineered fill, according to the Iraqi Standard Specifications for Roads and Bridges (SORB/R6) [33].

Table1. Soil properties.

Property	Value
Maximum dry density (MDD), g/cm ³	1.58
Optimum moisture content (OMC), %	10.52
SO ₃	0.013
Total dissolved salts, %	0.029
Total soluble salts, %	0.613
Specific Gravity (G _s)	2.67
Soil type	SP

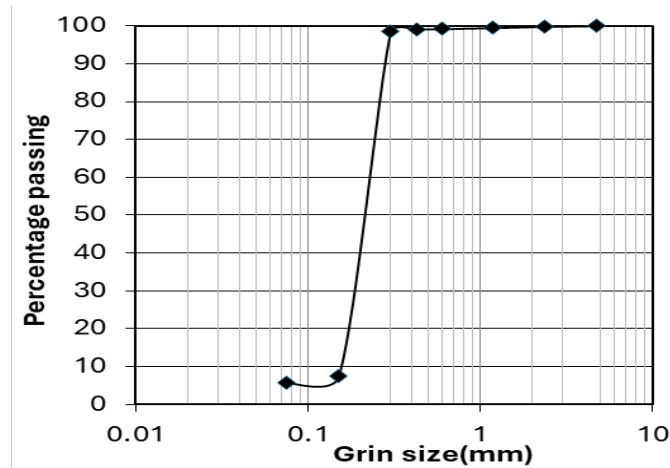


Figure 1. Grain size distribution curve for sediments.

Ordinary Portland Cement (OPC) was used for improvement in this study. The chemical and mechanical tests on the cement were conducted by the Construction Materials Laboratory at the University of Anbar. The physical and chemical properties of the used cement are listed in Tables 2 and 3, respectively. These properties were compared to the requirements of the Iraqi specifications for OPC (IQ. S No.5/1984) [34].

Table 2. Physical and mechanical properties of the OPC.

Property	Test results	IQ. S No. 5/1984
Initial setting time, min	190	≥ 45 min
Final setting time, min	315	≤ 600 min
Fineness, m ² /kg	303	≥ 250 m ² /kg
Compressive strength, MPa	3 days: 23 7 days: 29	≥ 15 MPa ≥ 23 MPa

Table 3. Chemical composition of the OPC.

SiO ₂	CaO	Al ₂ O ₃	Fe ₂ O ₃	SO ₃	MgO	L.O.I	I.R
19.43	61.34	4.62	5.35	2.28	4.36	3.21	0.96

PPF material, as shown in Fig. 2, used in this study to decrease deformation by increasing the tension resistance. The PPF is Sika fiber PPM-12 with the properties as listed in Table 4.

Table 4. The PPF properties.

Property	Description
Composition	100 % polypropylene
Appearance / Color	Transparent fibers
Density	~0,91 g/cm ³
Diameter	32 μm
Length	12 mm
Melting point	~160 °C
Specific tensile strength	~30 cN/tex

**Figure 2. Photograph of polypropylene discrete fiber (12 mm).**

2.2. Compaction Test

The purpose of this laboratory examination is to establish the relationship between the amount of moisture and the soil dry density under a particular compaction energy. The term "compaction energy" refers to the quantity of mechanical energy, which is exerted on a given soil mass. The standard Proctor test was used to compact the specimens. The ASTM D689 [35] outlines the standard testing procedures for determining the laboratory compaction properties of soil by employing a standard effort.

2.3. Unconfined Compression Strength (UCS)

For cohesive soils, the UCS test measures shear strength. The test performed without applying confining pressure, making it a simple and fast testing method. The experiment was carried on 12 selected specimens prepared from the soil before and after treatment. The UCS values for the prepared samples were obtained using the standard approach outlined in ASTM D2166 [36].

2.4. Specimen Preparation and Curing

The specimens used for the UCS tests were compacted under the predetermined MDD and OMC. The first set of specimens was produced by adding cement in three percentages of (4, 6, and 8 by weight of dry soil). These specimens were tested after 7 and 28 days of curing. Other set of specimens was treated by adding 0.5 % of PPF in addition to the specified cement proportions. The UCS specimen had to be two to three and a half times its diameter to meet the requirements of the test. Samples were compacted using the split compaction mold and a hammer. The mold had a diameter of 63 mm and a height of 128 mm. The soil in this mold was placed in three layers, with each layer receiving 11 blows for compaction. The number of layers and blows were calculated to accomplish the same standard compaction effort (600 kN.m/m³) as the conventional Proctor test, as presented in Equation 1.

$$\text{Energy } E = \frac{\left(\frac{\text{number of blow}}{\text{per layer}} \right) \times (\text{number of layer}) \times (\text{weight of hammer}) \times (\text{height of drop})}{\text{volume of mold}} \quad (1)$$

Soil specimens that had been treated were sealed with a nylon tape and stored at plastic bags for keep them wet until testing, whereas those that had not undergone treatment were tested immediately upon compaction. At a temperature of 25±2 °C, the specimens were left to cure for 7 and 28 days, respectively.

2.5. Durability Test

A durability test aim to observation a performance of the sediment materials with different cement ratios. The test was carried out, as per ASTM D599 [36], on both untreated soil and treated soil with different cement ratios of 4, 6, and 8 %. Two specimens were prepared using the same mold as for the UCS test. One specimen was used to determine the weight loss and the other to determine the volume change. The specimens were initially cured at room temperature 25 ± 2 °C for 7 and 28 days. Weight loss and volume change were recorded after each wet-dry cycle that the treated specimens underwent. The first step of the cycle was to soak the samples in water for five hours. After that, they were taken out of the water and their mass and dimensions were measured. The next step is to bake the specimens in an oven set at 105 ± 3 °C for 42 hours. Once a specimen is taken out of the oven, it is given two coats of brushstrokes on each surface to remove the adhered materials, as shown in Fig. 3. The other specimen was used (without brush strokes) to monitor the volume change by measuring the dimensions after each cycle. The technique was done 12 times and each cycle lasted 48 hours. Once the 12 cycles were completed, the specimens were baked at 105 °C until they attained a consistent mass. Using Equation 2, we were able to determine the specimen's weight decrease.

$$\text{Weight loss \%} = \frac{\text{initial weight} - \text{final dry weight}}{\text{initial weight}} \times 100. \quad (2)$$

To evaluate the possibility of specimen failure (collapse), its status was monitored during the wetting-drying cycles. Upon finishing the test and noting the volume change and weight reduction.



Figure 3. Photographs of the durability test specimens.

3. Results and Discussion

3.1. Compaction Test Results

To determine the MDD and optimal water content, a curve is plotted correlating the water content and dry density. The results of the compaction tests are presented in Fig. 4. The MDD value increased from 1.59 to 1.76 gm/cm³ when increasing the cement ratio from 0 to 8 %. The OMC value decreased from 10.33 to 9.2 % when increasing the cement ratio from 0 to 8 %. This trend may be attributed to the increase in physical properties of cement that has finer particle size with higher G_s which tends to fill the voids of the specimens.

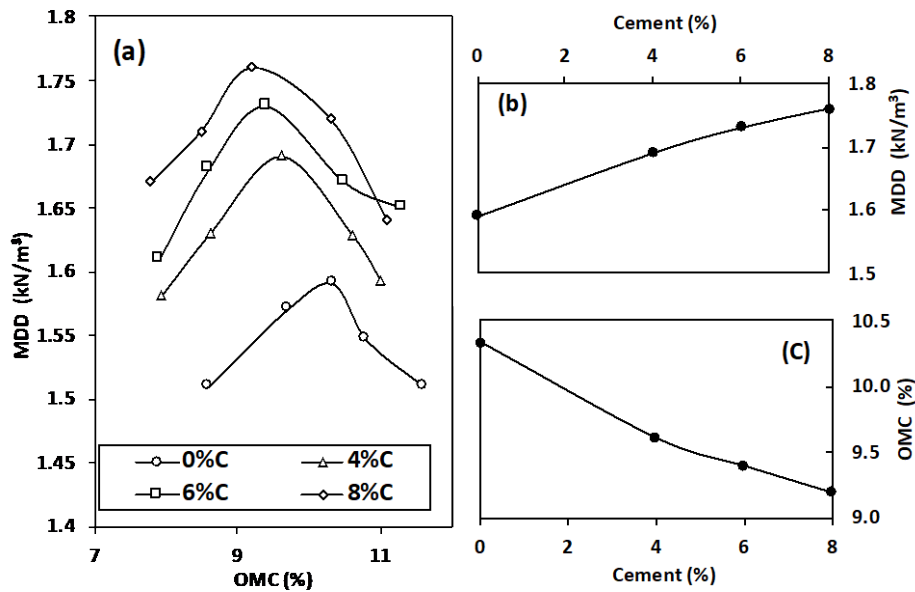


Figure 4. The compaction test results: (a) compaction curves; (b) cement-MDD relationships; (c) cement-OMC relationships.

3.2. The UCS Test Results

The USC test is convenient and cost-effective test to evaluate the shear strength in the laboratory to select the most suitable material for different geotechnical structures. The values of the UCS for specimens treated with cement (c) and cement-PPF (c-PPF) are shown in Fig. 5 and 6, respectively. Because the untreated soil is very loose poorly graded sand, the UCS could not be conducted on this soil. For the cement-treated specimens, the UCS values increased gradually with increasing cement ratio from 4 to 8 % for both curing durations because the increase in cement led to reduce the void ratio and increase the hardness of the specimens. Increasing cement ratio from 0 to 8 % led to increase the UCS values from 0 to greater than 2000 kN/m^2 . Moreover, using the PPF led to increase the UCS value for all curing periods, this is because PPF acted as reinforcement to the sediment particles. For optimum value, further experiments can be carried out with greater percentages of PPF, and compatible the results. A comparison between the two methods of treatment is presented in Fig. 7. For the curing period of 7 days, the UCS values increased from 29 to 46 % when PPF was added. Likewise, the UCS values increased from 9 to 52 % when the PPF was added for the curing period of 28 days. The figures also show that as the curing period increased from 7 to 28 days, the UCS values increased from 13 to 38 %. These results indicate the importance of providing sufficient curing time to develop the strength of cement-PPF treated soil.

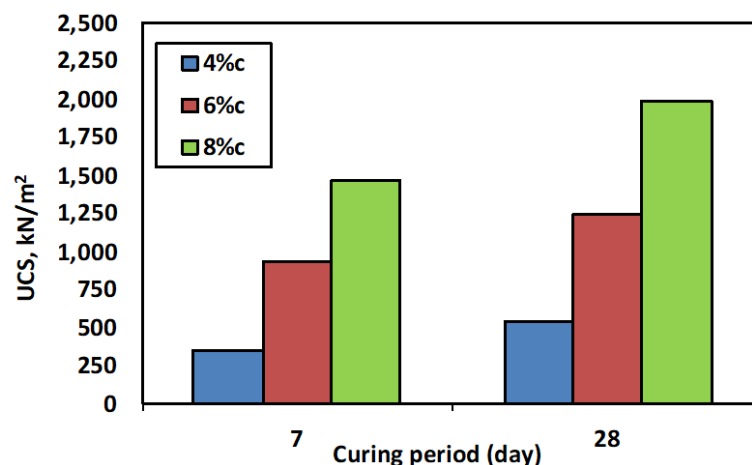


Figure 5. The UCS values for the specimens treated by cement.

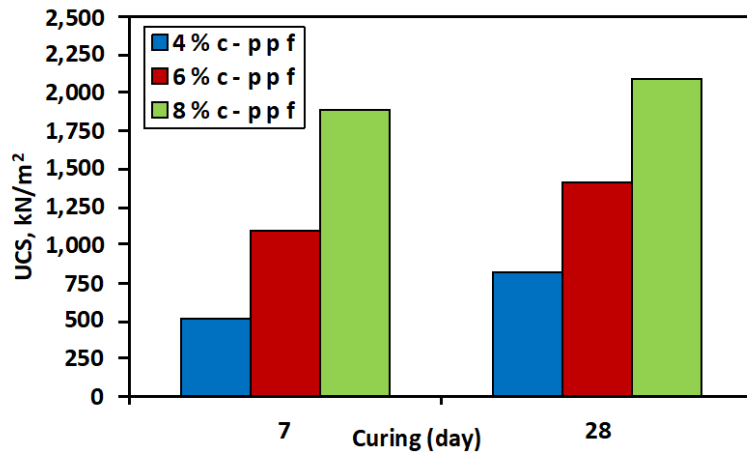


Figure 6. The UCS values for the specimens treated by cement and PPF.

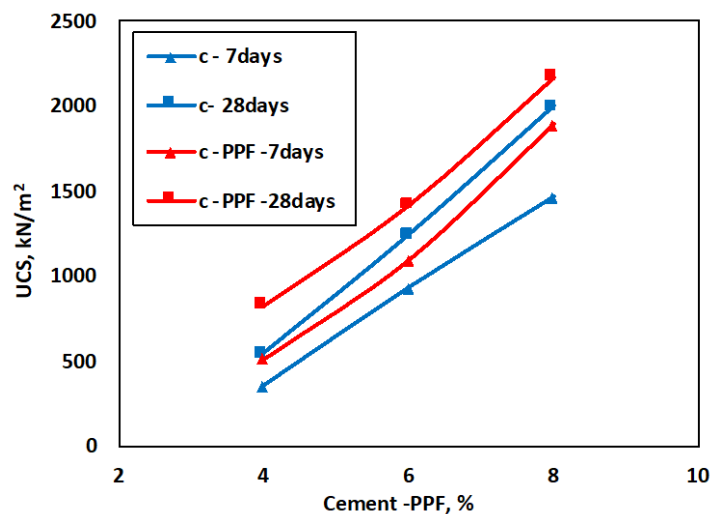


Figure 7. The effect of treatment methods on the UCS values.

3.3. Durability Test Results

The primary focus in the chemical stabilization of soils is ensuring long-term performance under different conditions. The composition of soil particles is affected by water, causing leaching of chemical components. This leads to inadequate soil stability, which is further impacted by seasonal variations and climatic circumstances. The durability test examines the volumetric stability and strength loss in the UCS using two approaches. The samples chosen for testing in wet and dry circumstances were produced using the optimal mixes determined from the UCS test. The weight loss, volume alteration, and durability of the samples were assessed after undergoing 12 cycles of soaking and drying, as shown in Table 5. The results showed the significant improvement in resistance for wetting and drying. The untreated specimens collapsed in the first cycle while the treated specimens successfully passed the cycles with loss in weight ranging from 16 to 39 %. These results indicate the feasibility of using these materials for earth structures that are exposed to severe change in climatic conditions such as earth dams and levees.

Table 5. The results of the durability tests.

Cement, %	Age, day	Weight loss, %	Volume change
0	–	Collapsed in the first cycle	–
4	7	39	No volume change
	28	34	
6	7	30	No volume change
	28	26	
8	7	22	No volume change
	28	16	

4. Conclusions

The objective of this research is to assess the effectiveness of employing OPC with PPF to stabilize dredged sediments for geotechnical engineering purposes. This study focused on investigating the mechanical, physical, and durability properties of sediments dredged from the Euphrates River. The findings of this research suggest that:

1. The sediment materials that were studied are classified as loose poorly graded sand that is not suitable as engineered fill.
2. Increasing the cement ratio from 4 to 8 % led to increase the MDD and reduce the OMC of the cement-treated compacted specimens.
3. Adding cement to the sand significantly increased the UCS, as the 8 % cement produced a UCS value as high as 2000 kN/m².
4. Applying PPF to cement-treated specimens led to an improvement in the UCS values that reached 52 %.
5. As the curing period increased from 7 to 28 days, the UCS values increased from 13 to 38 %.
6. The cement-treated specimens successfully passed the durability test with loss in weight ranging from 16 to 39 % compared to the untreated specimens that collapsed in the first cycle of wetting-drying.
7. The aforementioned results demonstrated that cement and PPF can be used as effective additives to improve the mechanical properties of loose sand sediments.

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