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Evolution of Some Geotechnical Soil Properties Improved with Phosphate Binder

Ibtehaj Taha Jawad
Department of Civil Engineering, College of Engineering, University of Babylon, Hillah, Iraq

Abstract: This study is devoted to evaluate the performance of low pH cement for the use in soil improvement. Soil samples were collected from a depth at 0.7 m below the ground level. A phosphate binder was used in this study. The soil treated with four different percentages of the binder. These percentages were 0, 3, 5 and 7% by the dry mass of the treated soil. The performance evaluation of the binder used was dependent on the results obtained from the compressive strength and microstructure tests of the base and treated soil samples. The obtained results indicated a considerable evolution in the soil compressive strength. Additionally, coherent and compacted microstructures were observed along with the formation of the cementitious products of phosphate cement. A reduction in pore voids of the samples of the treated soil was detected as well.

Key words: Soil improvement, soil microstructure, unconfined compressive strength, cementitious, performance, Iraq

INTRODUCTION

Since, soil improvement is one of important activities in many projects, cost effective and efficiency of method (materials) must be taken into account. In addition, sustainability and eco-friendly materials are very important factors to choose the suitable materials. Calcium based materials are considered the most common additive materials used for soil improvement. However, some disadvantages accompanied using such materials. Some of these disadvantages involved negative impact on the environment and energy consumption caused by production process and some deleterious chemical reactions due to carbonation and sulfate attack (Jawad *et al*., 2014; Mikulcic *et al*., 2013; Xu *et al*., 2012; Engin and Ari, 2005; Rajasekaran 2005; Raymond and Ouhadi, 2007). Based on these points, trying to find alternative stabilizers could be one of the priorities in the area of soil improvement.

Probably, phosphate binder is a good candidate for improvement of soil properties. It possesses high crystal structure, excellent bond, volume stability, early strength and affinity for organic media. In addition, it is durable and low permeable material (Yang *et al*., 2017; Zhang *et al*., 2017; Li *et al*., 2017; Viani *et al*., 2016; Ding *et al*., 2012; Gartner and Macphee, 2011; Chau *et al*., 2011; Gardner *et al*., 2015; Ma *et al*., 2014). So, this research aims to observe the evolution of microstructure and strength of soil treated with phosphate cement.

MATERIALS AND METHODS

Experimental program

Raw materials: After scraping the 70 cm top soil, a light brown soil was obtained. It is collected by plastic bag and translates to soil mechanics lab. The sieve and hydrometer analyses show that the soil consists of 59% sand, 25% silt, 16% clay fraction while the gravel fraction is null. On the other hand, the liquid limit and plasticity index are 25 and 12%, respectively. The standard proctor compaction test displays that the maximum dry density is 1.78 mg/m^3 and optimum moisture content is 16%. The soil is classified as SC according to unified soil classification system.

Magnesia (MgO) of a purity of >99.5% was supplied by inframat, advanced, materials, company, manchester, United State of America. The borax ($Na_2B_4O_7.10H_2O$) was provided by active, micro, fertilizer, company, Selangor, Malaysia. It is odorless white powder with purity exceeds 99%. Potassium Dihydrogen Phosphate (KDP) (KH_2PO_4) was sourced from green, life, agriculture, company, Shah Alam, Malaysia. It is of purity exceed 99%. The preparation of phosphate cement involved reaction between KDP and magnesia in presence of water and borax. Since, production of high crystalline binder associated with a reasonable rate of reaction, borax is used as buffering agent to control the rate of reaction. This role induced reduction the heat released by hydration and increasing the workability (Ding *et al*., 2012; Yang and Qian, 2010; Yang *et al*., 2013; Chong *et al*., 2017; Ma and Xu, 2017).

Laboratory tests: Unconfined compression test was adopted to evaluate the strength of original soil and strength evolution of treated soil over range of binder contents of 3, 5 and 7% by unit weight of dry soil. This test was conducted based on BS 1377-7:1990 by strain controlled machine. Standard proctor compaction test was conducted at maximum dry density and optimum moisture content to prepare all specimens. Each specimen was wrapped by a plastic thin film and cured for 24 h. The ambient room conditions were adopted as curing conditions. The mod of failure was observed following to each test. Samples from untreated and treated soil were used to observe the alteration in microstructure. Soil 7% cement specimen was picked out to be the represented sample for microstructure detection. As soon as the curing period elapsed, a sample was taken and comminuted. Thereafter, it was passed through sieve #100. The passed fraction was used for visualizing the microstructure under Field-Emission Scanning Electron Microscope. For original soil sample preparation, same procedure was adopted as well.

RESULTS AND DISCUSSION

Figure 1 shows the results of Unconfined Compressive Strength (UCS) test of the soil samples treated with phosphate binder after 24 h of curing. There was a noticeable development in soil strength after treatment compared with original soil as shown in Fig. 1. The results of UCS test indicated a continuous increase in the compressive strength with the increase of the binder percentage. Values of soil strength recorded 286, 534 and 615 kPa for the soil samples treated with 3, 5 and 7% of cement, respectively while it was 151 kPa for the pure soil (untreated soil).

The modes of failure of specimens subjected to unconfined compression test were presented in Fig. 2. All specimens including base soil exhibited brittle failure. However, two main modes were observed, splitting fracture in cases of base soil and 3% cement-soil mixture and shear fracture in cases of 5 and 7% cement treated soil.

The photomicrographs of different scales were obtained to elucidate the evolution of microstructure. The scales of 10, 2, 1 μm and 100 nm were shown in Fig. 3 for base and treated soil. The left-hand column of photomicrographs displays the original soil texture. Meanwhile, the corresponding column on the right-hand shows the texture of treated soil. From Fig. 3, it can be recognized that the apparent shape of soil particles became coarser after treatment due to the bonding action of phosphate binder. Where this binder acted to make the fine soil particles bond with each other making larger clusters (Photomicrograph a and b).

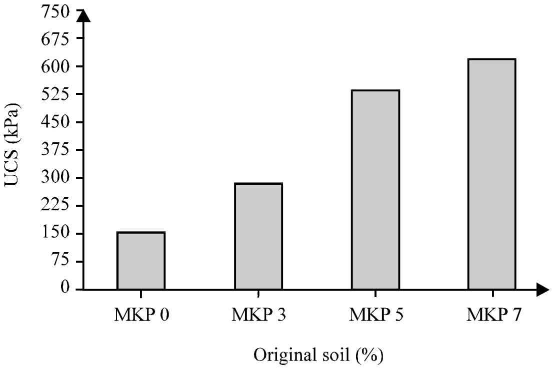

Fig. 1: Evolution of strength with different percentages of binder

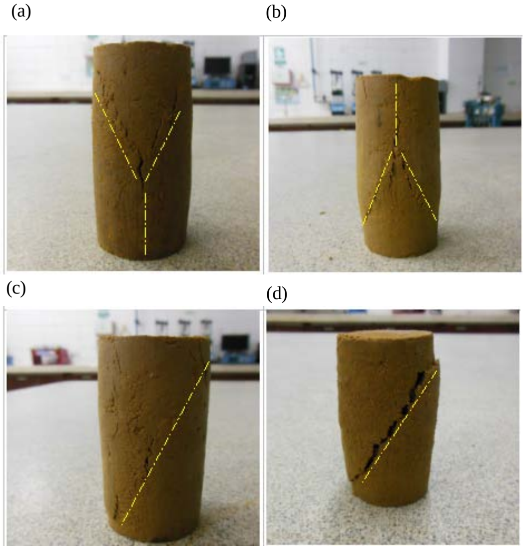

Fig. 2: Modes of failure for base and treated soil: a) Base soil; b) Binder 3%; c) Binder 5% and d) Binder 7%

Closer SEM images of untreated and treated soil are presented in Fig. 3c and d. At the image d, a new compound can be recognized in the microstructure of the treated sample when comparing with the image of the untreated soil (Fig. 3c) which can elucidate the formation of cementitious products of phosphate cement.

Figure 3e and f display the micrographs of virgin and soil mixed with binder at an extra zooming value. At this figure, flocculated platy particles can be observed in both figures. However, the micrograph of the mixed soil shown in the image F indicated denser, compacted and coherent microstructure than that of the untreated soil shown

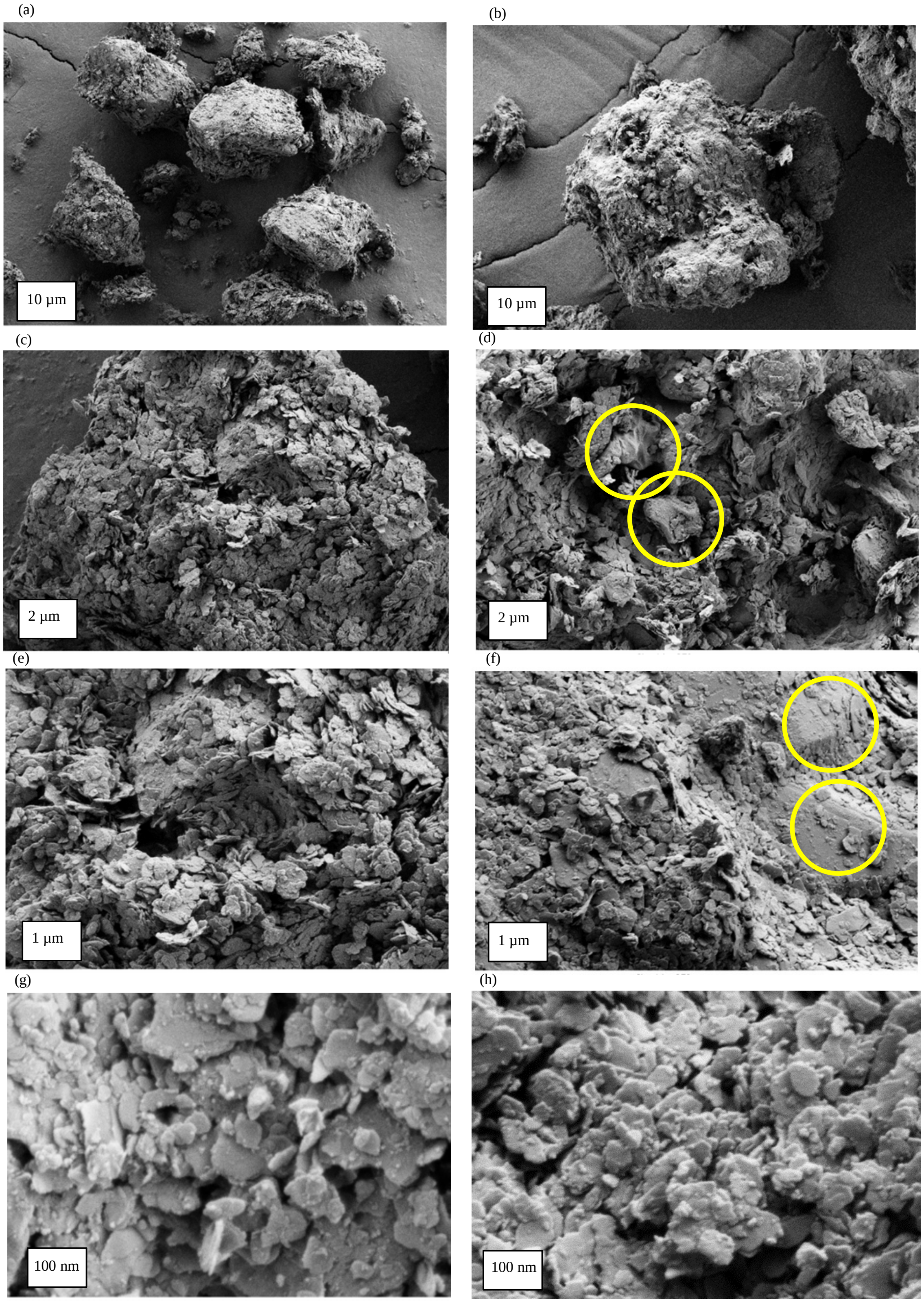

Fig. 3: Photomicrographs of base and treated soil

in the image e. This can confirm the formation of the cementitious products which has the responsibility to improve the geotechnical properties of the treated soil in this study. The images of Fig. 3g and h exhibit the structure in nano scale. It is seemed that the soil packing is less pore voids and denser in the case of treated soil.

CONCLUSION

As per the results obtained from the experiments in this study, the following conclusions can be drawn. Significant increments were observed in the unconfined compressive strength of the treated soil and the UCS increased with the continuous increase in the phosphate binder percentage. Substantial changes in the microstructure of the samples of the treated soil were occurred. Firstly, the particle size of the treated soil appeared larger than that of the pure soil. Secondly, a cementitious gel like structure was observed for phosphate cement which covered and bonded the soil particles to each other. Thirdly, due to the reduction in voids volume of the treated soil, a coherent and compacted soil structure was achieved.

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