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The Effects of Slaking on the Durability of Bio-improved Sand

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Abstract— Sustainable development perspectives confine to improve the geotechnical properties of weak soils by using such a material which has high engineering performance, less environmental impacts and is cost effective. Moreover, the eco-friendly-improved soil should also be resistive against the adverse environmental factors. So, the present paper focuses on the effects of wet-dry cycles on the durability of bio-improved sand. Xanthan gum (biopolymer) was used to improve sand collected from Muscat, capital city of Oman. The specimens prepared by mixing biopolymer and ordinary Portland cement with the sand were cured for 7, 14 and 28 days in controlled laboratory environment. Standard slake durability tests were peformed on the specimens to determine the slake durability index after each wet-dry cycle. The results indicated that a small proportion of biopolymer treatment to sand had similar slake durability characterstics which are comparable to the treatment with a high proportion of cement. However, in the environment friendly perspective, cementation induced by biopolymer takes precedence over the Portland cement. The qualitative description of biocemented sand elucidated by micrographs taken by scanning electron microscope (SEM) inferred the enhanced durability to the connection of sand particles through biopolymer. The authors believe that present study will contribute in the development of techniques for the application of biopolymer in eco-friendly ground improvement.

Index Terms—bio-improvement, slaking, granular material, durability

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1 Introduction

ANTHROPOGENIC global warming is not only responsible for the rise in sea levels and abnormal climate problems but is also due to geo-environmental hazards from the unsustainable geotechnical systems supporting the civil infrastructure. Both new construction sites and rehabilitation works on weak soils require ground improvement. Over the past century, various ground improvement methods have been developed, and today many of them are widely employed to build geotechnical systems. It is appropriate to classify a wide variety of soil treatment methods as mechanical or chemical. Mechanical methods improve the soil by densification/dewatering, however in the chemical methods cementation is induced mainly by ordinary Portland cement or chemical additives. The basic principles of these techniques have not changed since the early of the twentieth century. The practices, however, have been changing with the time mainly because of the development of new materials, new machinery, and new technologies. Largely unrecognized by geotechnical engineers is the influence of geotechnical construction processes that can be on biodiversity [1].

Some of the products used in soil improvement are not considered as environment friendly due to high emission of greenhouse gases during their production and toxic nature after application. The addition of these materials, while beneficial from an engineering performance perspective, might not necessarily be advantageous for the environment. Ordinary cement production emits carbon dioxide, a significant greenhouse gas, during chemical calcination and fuel burning. It has been reported that 5% of the global carbon dioxide emissions are induced by the cement industries [2]. Alternative, natural biologically – based treatment methods could meet the same engineering requirements without environmental concerns. Therefore, demand for the development of environmentally friendly construction materials that are relatively harmless and easily reused without environmental impacts is increasing significantly in the 21st century [3]. The great promise of the use of biological treatments has been already demonstrated in other fields such as in petroleum industry to directing the oil flow in the required direction, in concrete technology to remediate cracks [4], development of shields for zonal remediation and stabilization of contaminated soils [5].

Biopolymers are polymers produced by living organisms, and most biopolymer applications are in the field of medical engineering, such as drug delivery systems, wound healing, and surgical implantations [6]. More recently, research in biology and earth science has enabled important advances in understanding the crucial involvement of microorganisms in the evolution of the earth, their ubiquitous presence in near surface soils and rocks, and their participation in mediating and facilitating most geochemical reactions [7]. According to Ivanov and Chu [8], biocementation can replace the high energy demanding mechanical compaction or the expensive or environmentally harmful chemical grouting. To achieve the aim of environment friendly development, in the fields of soil science, geotechnical engineering, and geo-environmental engineering, biopolymers have been employed as soil stabilizers to enhance the mechanical response of ground against the external loading and the environment. In the overview of past attempts in recent time, laboratory studies were conducted to determine the change in soil properties due to the biocementation either directly induced by microorganisms or by treatment with the biopolymers produced by microorganisms. Ca-

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balar and Canakci [3] and Chang et al. [9] used xanthan gum to improve the strength and the resistance to erosion persuaded by water flow, respectively. Most of the studies set their focus on the qualitative demonstration of the biocementation by using the latest techniques of microscopy. Improvement in the mechanical behaviour of soils due to biocementation was also explored by the traditional element tests, i.e. triaxial tests [1] direct shear tests [3] and uniaxial compression tests [10]. Based on the above studies, the authors intend to use the commercially available biopolymer xanthan gum to induce biocementation in local Omani sand. The authors revealed that the behavior of bioimproved sand can be affected when subjected to wetting and drying cycles in the environment. Therefore the present study explores such effects by conducting the slake durability tests on bio-improved and cement treated sand.

2 Methodology

Sand from Muscat is sampled to induce cementation by mixing it with bio-polymer. Standard slake durability device is used to elucidate the slake durability indices of bio-improved and cement treated sand. SEM is employed to demonstrate the bonding between granular media

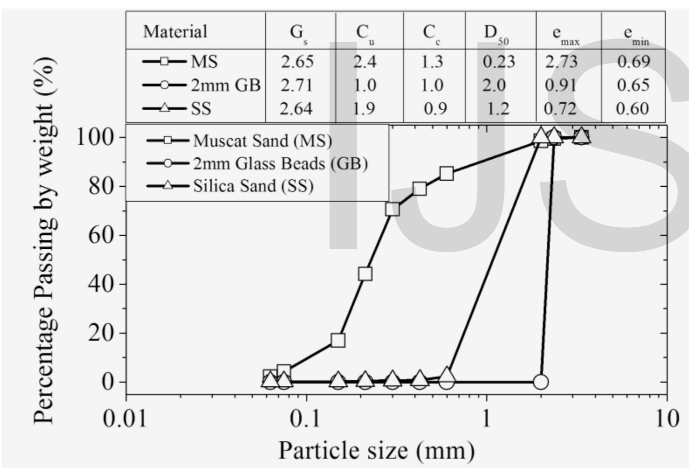

Fig.1. Physical properties of sand and standard materials [11]

2.1 Materials

The representative sand was sampled from the Muscat, Capital of Oman. Muscat sand (MS) has a fines content of around 5%. The sand is formed due to the mechanical weathering of sedimentary rocks, among which limestone is dominant. The physical characteristics of MS along with its comparison to the standard silica sand (SS) and 2mm glass beads (GB) is shown in fig 1. According to the Unified Soil Classification System the MS is classified as SP (poorly graded sand). A wide range of void ratios (2.73 to 0.69) can allow the ubiquitous distribution of cementing material for cementation and consequent increase in strength [11].

A commercially available bio-polymer, xanthan gum (XG) which has high demand in the food industry is used in the present study for the bio-treatment of MS. Xanthan gum used in the present study was marketed by Blackburn Distributors Ltd under the product specification FCC IV, E-415, USP23/24. Xanthan gum is an anionic polysaccharide composed of D-glucuronic acid, D-manomers, pyruvylated mannose, 6-O-acetyle D-Mannose and a 1, 4-linked glucan [12]. The viscosity of xanthan gum solutions decreases with higher shear rates; this is called shear thinning or pseudo-plasticity. This means that a product subjected to shear, whether from mixing, shaking or even chewing, will thin out, but once the shear forces are removed, the food will thicken back up. In the oil industry, xanthan gum is used in large quantities, usually to thicken drilling mud. These fluids serve to carry the solids cut by the drilling bit back to the surface. It has also been added to concrete poured underwater, to increase its viscosity and prevent washout. Moreover, XG shows high stability under a wide range of temperatures and pH [13].

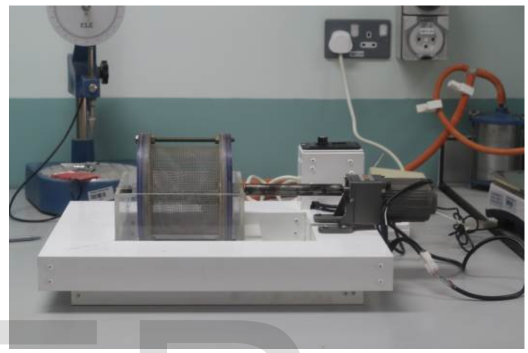

Fig.2. Standard Slake durability device at Sohar University, Oman

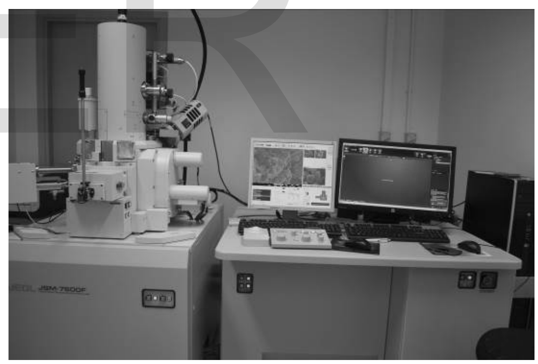

Fig.3. Field Emission Scanning Electron Miscroscope (SEM) at Sultan Qaboos University, Oman

2.2 Equipment

A standard Slake durability device [14] was manufactured for the present study and is shown in fig. 2. It is composed of 2mm wire mesh drum of length 100mm and diameter 140mm, which is coupled to a motor (20rpm). The wire mesh drum rotates in water levelled 20mm below the axis of rotation. Ten pieces (40 to 60 grams each) representative specimen are weighed and put in to the drum. The drum rotates at 20 rpm for 10 minutes in water. Retained specimens in the drum are considered for the quantitative assessment of durability. The wet-dry tests were started by taking the initial weight of the oven dried (105°C) specimens (10 pieces of 40-60gm each). After cooling down at room temperature they were put into the standard durability apparatus and processed as stated earlier. The percentage ratio of dry retained weight after each

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cycle to the initial dried weight gives the slake durability index. A JEOL, JSM-7600F, field emission scanning electron microscope (SEM) was used to capture the images of bio-treated and untreated sand particles. The SEM employed in present study is showen in fig 3.

2.3 Specimen Preperation

It was essential to maintain consistency between the specimens prepared for testing. Therefore, great care was taken to have reasonable repeatability during the preparation of specimens. Xanthan gum in the powered form was mixed in sand and water. The trial percentage of gum was kept 3% (MSG3) and 5% (MSG5) by weight of the mix. First the required quantity of xanthan gum was mixed with distilled water in the laboratory automatic mixer to form a jelly. Afterwards the weighted sand quantity was added gradually in the jelly of xanthan gum to make a homogeneous mix [11]. In line with the traditional ground improvement of sand by using cement, 10% by weight is added to Muscat sand [15]. The steps of specimen preparation in the case of cement treated sand (MSC10) were same as that for xanthan gum treated sand, except the use of cement instead of the gum. The time dependent change in the bulk unit weight is shown in fig 4. There is no significant change in the bulk unit weight of treated sand over the curing of 28 days which indicates the stability of treated sand over the observed duration.

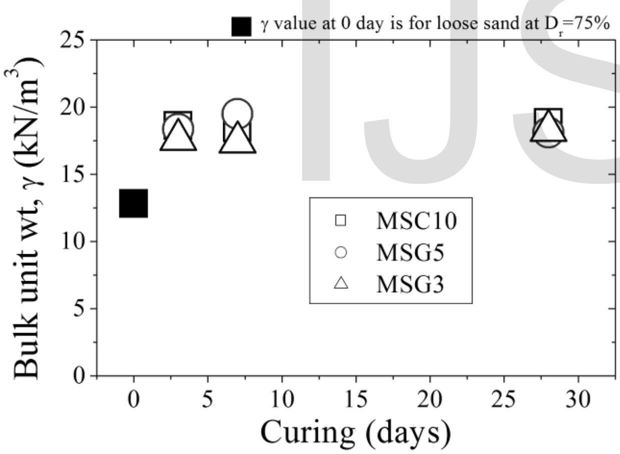

Fig. 4. Time dependent change in the bulk unit weight of treated Muscat sand [11]

3 Experimental Results

In order to investigate the durability of bio-improved sand, standard slake durability tests were performed on bioimproved sand and cement treated sand. Instead of performing 2 standard cycles [14] of wetting and drying, four cycles were performed to determine the robust slake durability index. The test results are shown in fig. 5 indicate that the slake durability index decreases with increase in slaking cycles. It is also evident from fig. 5 that the reduction rate of slake durability index decreases with increase in slaking cycles. MSG3 offered highest resistant to slaking as compared to MSG5 and MSC10. A pictorial record of specimens undergoing slaking cycles shown in fig. 6 qualitatively defines the results presented in fig.5.

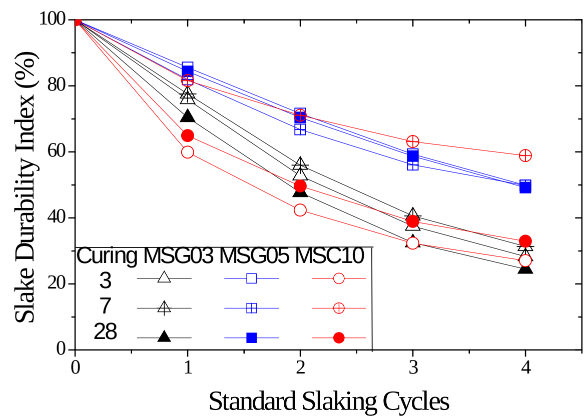

Fig. 5.Slake durability test results of bio-improved and cement treated.

Fig. 6.A typical pictorial record of specimens after slaking cycles

The microstructure of biopolymer treated soil was observed under the SEM. Fig 7(a) shows the SEM image of sand particals in loose state. The SEM images of biotreated sand are illustrated in fig. 7(a) which shows the bundled soil particle around the biopolymer. Biopolymer has taken place of the voids between the loose materials. Theng [16] stated that the polymer surface conformation can be classified into three modes: directly attached "trains", three dimensional "loops" and two freely suspended "trails". The fraction of train segment governs the interaction between soil grains and the pol-

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ymer. The external loading on biocemented sand is resisted by a blend of interconnected soil particles through the biopolymer trails. According to Chang and Cho [10] in their study on beta glucan biopolymer, for granular soils (non-charged) the adsorption of biopolymer on the particle surface and consequent enlarged surface area governs the inter-particle behaviour, while biopolymer overarches the detached particles. In fig. 7(b), the xanthan gum treated sand elucidates a similar behaviour.

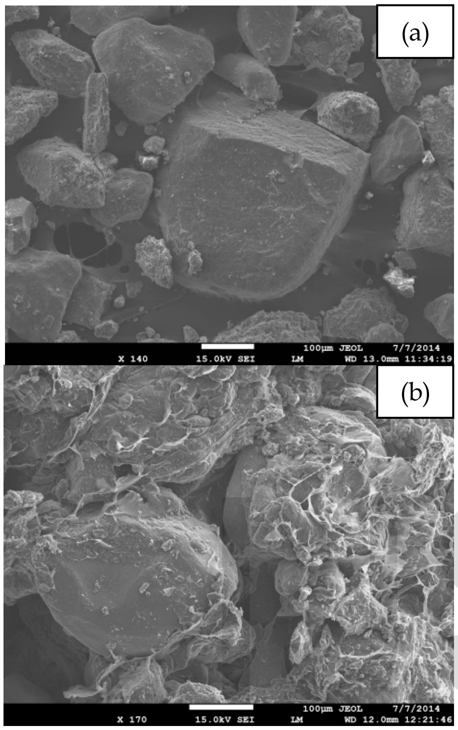

Fig. 7.SEM Images of (a) Untreated and (b) bio-treated Muscat Sand

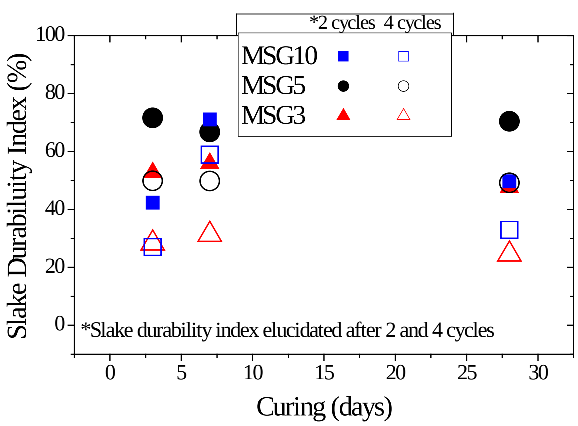

Fig. 8.Effects of curing in slake durability indices

4 Analysis and Discussion

It is evident from fig. 5 that the slake durability index of bio-improved sand is compareable to cement treated sand. MSG5 offered the highest resistance to disintegration against slaking. The effects of curing days in this study are not very significant. The slake durability indices obtained after 2 and 4 cycles for MSG5, MSG3 and MSG10 are plotted against the curing days in fig. 8. In the case of 2 cycles slake durability index MSG5 showed the highet durability against slaking, same is the case for 4 cycles durability index. So it can be concluded that the MSG5 with high proportation by weight of biopolymer in comparison to MSG3 is more durable against slaking. The proportional level of biopolymer can be studied in detail for the optimization. Another study on the similar sand, Qureshi et al. [11] conducted that the MSG5 gained higher cohesion as compared to MSG3 and MSC10. They also concluded the increase in internal friction angle of bio-improved sand, however there was not much difference between MSG5 and MSG3 after 28 days of curing.

5 Conclusions

The authors derived following conclusions from this research.

1. The bio-improved sand also offers resistance to disintegration due to slaking similar to the natural intact geomaterial.
2. Bio-improvement of sand done with high proportaion of biomaterial proved more durable.
3. The durability trend of bio-improvemnt can be related to the strength gained due to the improvement.
4. The SEM studies also elucidated that the resistance to durability is inferred to the strong micro connection between the sand particles.

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