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A novel study on using protein based biopolymers in soil strengthening

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HIGHLIGHTS

- Casein and sodium caseinate biopolymers were used to stabilize dune sand.
- UCS, CBR, direct shear and leaching tests were conducted on stabilized samples.
- Micro structure was studied by SEM method and a descriptive model was developed.
- The modifying effect of casein was compared with gellan, agar, xanthan and lignin.

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ABSTRACT

New protein-based biopolymers are introduced in this study to stabilize dune sand. Since the conventional soil stabilization materials, especially cement, have harmful effects on the environment, alternative eco-friendly materials, casein and sodium caseinate salt biopolymers have been used in this study to reduce environmental concerns. Casein and sodium caseinate biopolymers obtained from milk were added to dune sand, and mechanical properties of biopolymer treated sand were investigated through a series of laboratory tests. The effects of biopolymer content, curing time, curing temperature, and fat milk content on improving sand were studied by unconfined compression test. The results showed that compressive strength of biopolymer treated sand was increased when the curing time had passed, and biopolymer content increased. Moreover, temperature can be effective on improving compressive strength of samples treated by casein and sodium caseinate. The positive influence of curing temperature on compressive strength of modified soil was estimated to be up to 60 °C. In addition, direct shear test, leaching test and California bearing ratio (CBR) test alongside microscopic observation by scanning electrons microscopy images (SEM) were performed. On the whole, the protein-based biopolymers propose a strong potential as additives for soil treatment rather than some material such as cement and chemical polymers.

1. Introduction

Soil treatment is an essential concern for geotechnical engineers because of urbanization and population growth throughout the world. Generally, ground improvement aims to resolve various geotechnical problems such as reducing differential settlements of foundations, improving mechanical parameters of subgrade layers, consolidation and compaction of the soil, and the improvement of shear strength [1]. For these purposes, various methods and materials have been used till now. Among them, cement is the most widely used additive owing to adequate strength, availability, and low cost [2]. In spite of advantages and various applications of cement, it has caused numerous detrimental impacts on the environment [3].

It should be noted that during production process of cement, about 0.95 ton CO_2 per ton of cement is imposed into the atmosphere [4]. Whereas, the rate of CO_2 production by cement industries has risen in the last few years from 4.2% in 1980 to 9.0% in 2012. The proportion of geotechnical projects is also almost 2% of total CO_2 emissions produced by cement [3]. Global warming is one the harmful effects of increasing the amount of greenhouse gases [5]; besides, glacier melting and rising sea level [6], intense storms and tornados, and drought are all consequences of global warming [7]. Moreover, changing the soil pH, urban runoff, preventing the surface vegetation growth, and concrete dust are other environmental drawbacks of using cement [3].

Therefore, in the current century, environmental concerns have led to the use of different eco-friendly methods and materials in

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geotechnical activities. For this, useful bacteria and enzymes have been employed in endeavors towards soil improvement [3]. Although the microbial method has been satisfying with acceptable performance, some factors make this procedure complicated. In this manner, numerous environmental parameters such as temperature, pH, concentration of electron donor and electron acceptor, and the rate of nutrients and metabolites are simultaneously effective to gain adequate achievement. Moreover, microbial soil treatment is slightly more time-consuming compared with other methods [8].

A biopolymer is a polymeric substance (as a protein or polysaccharide) formed in a biological system [9]. The use of biopolymers in civil engineering activities dates back several years ago. But, it has been considered more frequently in recent years by civil engineers [3]. Lignin is the most abundant organic polymer existed on earth after cellulose [10]. The influences of Lignin, which is the third largest part of agricultural biomass, have been studied in different geotechnical aspects such as constitutive model for lignosulfonate-treated soil [11], thermal, mechanical, and microstructural characteristics of lignin treated soil [12–15], and Transportation infrastructure [16–18]. The optimum moisture content of lignin for improving silty soil was reported 12% by Zhang et al. Gaining the maximum compressive strength of lignin treated silt required 28 days of curing, also lignin changed the physicochemical behavior of sand minerals to provide a resistant lignin treated silt [12].

In recent years, new ecological materials have been introduced to reduce hazard environmental impacts of traditional additives; in this regard, two thermo-gelation biopolymers (gellan gum and gar gum) were evaluated by Chang et al. (2012)., which enable hydrogen bonds to enhance the strength and durability of sandy and clayey soils. While time was not a crucial parameter, thermal conditions played a very important role in soil treatment [19]. Chang et al. also introduced xanthan gum and b-1,3/1,6-Glucan biopolymer to improve the geotechnical behavior of different types of soils [20,21]. Furthermore, many other biopolymers including tannin [22], Alginate [23], Guar Gum [24], and starch indicate that the use of biopolymers would be operational and effective in soil strengthening. The studies show that biopolymers could be considered an environment-friendly alternative for soil improvement and mixed directly with soil, so this may resolve the need for providing complex conditions regarding microbial injection method [8].

In this study, Casein and sodium caseinate salt biopolymers are introduced as new soil additives to improve the geotechnical behavior of poor graded sand. How to produce Casein biopolymer from milk and its chemical characteristics are also described. Furthermore, the mechanical and geotechnical behavior of sand treated by Casein is investigated through a series of laboratory experiments. Besides, the interaction between soil and casein particles is represented by SEM images.

2. Materials and methods

2.1. Casein and sodium caseinate biopolymers

Casein is a protein-based biopolymer making up 80% of the proteins of cow's milk [25]. Casein has been derived from the Latin word "Caseus" which means cheese [26]. The isoelectric point of casein is about 4.6 and generally, the casein pH is 6.6 and has a negative charge. Casein chemical formula is C_{31} H_{27} NO_4 [27]. Casein and sodium caseinate salt as the additives have been used in this paper. When milk becomes sour, it separates into curd and whey are prepared, now by separating the water, casein is introduced. Casein can also be extracted from the milk by reducing the milk pH and adding a mineral acid into the milk [28].

The best quality of casein is gained when the fat milk and acid amount are in the lowest content [29]. So that the skim milk was used for this purpose. Then, the casein were washed after separating it from the milk to reduce the acid content. Casein, with its cheesy state, is insoluble in water. When sodium hydroxide is added to casein, the reaction between them produces sodium caseinate salt, which is a water soluble glue [27]. The produced moisture causes the sodium caseinate to be in the form of a paste and more appropriate for making a homogenous mixture compared with the cheesy texture of casein (see Fig. 1).

2.2. Soil

Iran is a country with an arid climate and covered by deserts such as Dasht-e Loot and Dasht-e Kavir. So that facing to dune sands of deserts, which categorized as poor soils, environment in constructional projects is inevitable. Uniform soil gradation, lack of cohesion among soil particles, high settlement, and low geotechnical strength are the main problems of dune sand. So, owing to the immense amount of dune sand throughout the world, improving the geotechnical parameters of loose granular soils and dune sand is essential.

In this study, the dune sand was collected from a highway construction site in Kerman, Iran. According to Table 1, the optimum moisture and maximum dry density contents were 1.74 g/cm^3 and 16%, respectively obtained from the standard Proctor compaction method based on ASTM D2216 [30]. Sieve Analysis were performed and the results are presented in Fig. 2. Since more than 95% of sand grains were larger than 0.075 mm and smaller than 2 mm, the soil was a poorly graded sand (SP) according to the Unified Soil Classification System (USCS). As material is transported, it is subject to abrasion and impact with other particles which tends to "round-off" the sharp edges or corners. This can be seen in Fig. 9a. the soil structural composition is between e_{min} = 0.6 and e_{max} = 0.78, the specific gravity (G_s) was also 2.63. Based on XRD test results (Table 2), the soil includes different types of materials: silica (SiO_2) by 55.66%, thallium sulfide (Tl_2S) by 13.13%, InO_3 by 11.39%, $Ba_3Ta_2ZnO_9$ by 4.97%, $Rb_6Te_2O_9$ by 9.63%, and $Li_9KNb_{10}O_{30}$ by 5.22%.

2.3. Specimen preparation

The soil was mixed with different weight ratio of casein and sodium caseinate. For all experiments, three tests were repeated for each sample to ensure that the results are accurate and the average values were reported for each treatment, and the variation with average value was considered less than 5%. The biopolymer-sand mixture placed into the special molds; for unconfined compression test, the molds were 36 mm in diameter and 75 mm in height based on ASTM D2166 and were made of polypropylene to prevent samples sticking to the walls. Furthermore, a linear groove was cut into the mold to extract samples more easily. While the specimens were being made, this groove was blocked by two pipe fasteners at the top and bottom of molds. Upper and lower surfaces were slightly trimmed to avoid non-uniform distribution of stress. In addition, two filter papers were put on the top and bottom surfaces to prevent stress localization. Direct shear test specimens also were fabricated in the metal molds and compacted at two layers that were 20 mm in height and 63 mm in diameter. All specimens were prepared by optimum moisture content and maximum soil dry density.

2.4. Experimental program

The dune sand was completely air dried so that the designed amount of additives and water were measured based on dry den-