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Strength durability of gellan gum biopolymer-treated Korean sand with cyclic wetting and drying

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HIGHLIGHTS

- Strength durability of gellan gum biopolymer is verified in this study.
- Wetting and drying cycles are performed on gellan gum-treated sand.
- Unconfined compressive strength was measured with cyclic wetting and drying.
- Gellan gum-treated sand shows hysteretic strength path along wetting-drying cycles.
- Dry strength remains 80% even after severe wetting-drying cycles.

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ABSTRACT

Various biological approaches recently have been explored as alternative environmentally-friendly soil improvement strategies in the fields of construction and geotechnical engineering, with the aim of reducing the use of high greenhouse gas emitting construction binders such as cement. Previous studies have shown the effectiveness of microbial biopolymers in soil improvement. However, there are still concerns about the durability and serviceability of biopolymer treated soils, resulting from the biodegradation and hydrolysis behaviors of the biologically produced compounds. In this study, the strength and durability of gellan gum biopolymer treated *Jumunjin* sand (standard sand of the Republic of Korea) was evaluated under cyclic wetting and drying. The results obtained indicate that the cyclic wetting and drying of gellan gum-treated sands results in a gradual degradation of strength, due to the dissociation of the gellan gum monomers under wetting and imperfect recomposition during re-drying, with an approximately 30% strength reduction over 10 cycles. However, a certain degree of strength recovery and resistance was observed even after numerous cycles, indicating that gellan gum-treated soils can potentially be applied for temporary or medium-term purposes in practical construction.

1. Introduction

Recently, several attempts to strengthen soil using biological processes or excretions (*e.g.*, biologically produced materials) for construction and geotechnical engineering applications have been reported [1–3]. For example, microbes such as *Sporosarcina pasteurii* have been injected into sandy soils to precipitate calcite between soil particles, which induces a cement-like effect but with a low carbon footprint [4–7]. Meanwhile, biologically produced biopolymers have been used directly as mixing additives or binders for soil improvement and strengthening, and have shown remarkable enhancement of inter-particle interactions, even at low concentrations (*e.g.*, a 1% or lower ratio to the mass of soil has yielded unconfined compressive strength higher than 4 MPa) [8–11]. A previous study involving the use of xanthan gum biopolymer for soil strengthening showed that xanthan gum mixed at 1% content with Korean residual soil increased the compressive strength (4.9 MPa) almost twofold relative to the compressive strength (2.6 MPa) of 10% cement treatment on the same soil [12]. Recent studies introduced thermo-gelation biopolymers such as gellan gum and agar gum as a new soil treatment binder for clayey and sandy soils [9,13]. Differences in soil types become important when considering biopolymer-treated soils: both gellan gum and agar gum exhibited especially significant strengthening

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efficiency with clayey soils (reaching up to 13 MPa for clayey soils) [9]. For pure sand, gel-type biopolymer treatment provides inter-particle cohesion on cohesionless soil which results in significant ground bearing capacity increase [13].

Biological approaches have environmentally-friendly advantages due to their low greenhouse gas emissions [14,15] and high ability to prevent soil erosion [16], whereas cement, the most commonly used binding material in the field of construction and building engineering, is known to contribute heavily to carbon dioxide emissions (*i.e.*, cement production accounts for approximately 7% of total global emissions) [17,18]. In light of growing environmental concerns, new construction materials [8,12] and methods [19,20] involving the use of biological processes and compounds (*e.g.* calcite precipitating micro-organisms, biopolymers) are being actively studied to reduce the usage of cement in the field of construction, especially for geotechnical engineering.

The main characteristics of cement that led to it becoming the most commonly used material in construction and geotechnical engineering are its excellent durability and serviceability [21]. Solid cement-aggregate mixtures (*i.e.*, concrete) are known to have a long service life depending on service conditions, and in some cases have been designed so that their service life is greater than 100 years [22]. Heterogeneous cement-soil mixtures (*e.g.*, deep cement mixed soils) also endure for many years depending on the site application type (*e.g.*, auger mixing, jet injection) and service conditions [23]. In contrast, biological excretions and compounds accompany concerns regarding their biodegradation and hydrolysis [24,25].

Although recent studies on soil strengthening using polysaccharide type biopolymers have shown significant strengthening due to direct hydrogen bonding and matrix formation with clayey particles [9,12,26], the factors affecting the durability and strength behavior of biopolymer treated soils should be considered and verified to ensure the broader usage of biopolymers as reliable construction and geotechnical engineering materials in practical implementations. In particular, sandy soil is expected to show poor durability because it does not directly interact with biopolymer molecules [12].

In a previous study it was shown that when thermo-gelating gellan gum biopolymer was used as a sand treatment and improvement material, and the treated sample was submerged in water, the unconfined compressive strength of the 1% gellan gum-treated sand suddenly diminished to 1/10th of the unconfined compression strength of the dried state [9]. Moreover, the strength of gellan gum-treated sand that was re-submerged (that is, submerged twice) was reduced to 1/5th of the strength of single-submerged gellan gum-treated sand (250 kPa) for the same gellan gum concentration (*i.e.*, 1%) and water content (*i.e.*, around 25%) conditions [9]. In this light, in order to test the durability concerns of gellan treated samples in relation with the moisture content, repeated drying and wetting cycles were performed in this study.

Because gel-type biopolymers generally show minimal or virtually no interaction with cohesionless sand, due to the neutral surface of the sand particles [12], sand is an appropriate soil type for clearly examining the strength behavior of gel-type biopolymers. For this reason, the durability, that is, the reduction in strength of gellan gum biopolymer treated sand under cyclic wetting and drying, was evaluated in this study through laboratory programs.

2. Experimental program

2.1. Materials

2.1.1. Sand

Jumunjin sand, which has served as a standard and is the most commonly adopted sand in Korea [9,27,28], was used. Jumunjin sand is classified as a poorly graded sand (SP) with a specific gravity of 2.65 and mean grain size (D_{50}) of 0.52 mm, where the uniformity coefficient (C_u) and coefficient of gradation (C_c) are 1.94 and 1.09, respectively. Jumunjin sand has a structural composition between $e_{min} = 0.64$ and $e_{max} = 0.89$, having an inter-particle friction angle (ϕ) of 29.3°. The particle size distribution curve of jumunjin sand can be seen in Fig. 1.

2.1.2. Gellan gum biopolymer

Gellan gum is a high molecular weight polysaccharide fermented from the *Sphingomonas elodea* microbe [29]. In this study, a low acyl gellan gum biopolymer purchased from Sigma Aldrich (CAS No: 71010-52-1) was used for the experimental programs. Low acyl gellan gum is an efficient gelling agent that is capable of forming gels even at low concentrations of 0.05–0.25%, and it also has excellent thermal and acid stability [30,31]. Low acyl gellan gum partially hydrates to form viscous gels in cold water, while temperatures above 80 °C are required to fully hydrate gellan gum monomers to form a uniform hydrocolloid state. Once heated, if the gellan gum hydrocolloid is then cooled to temperatures below 40 °C, the hydrocolloids are transformed into firm hydrogels. This transformation is accompanied by a remarkable increase in viscosity [32]. Gellan gum hydrogels begin to interact via hydrogen bonding with clayey particles, instead of water molecules, when

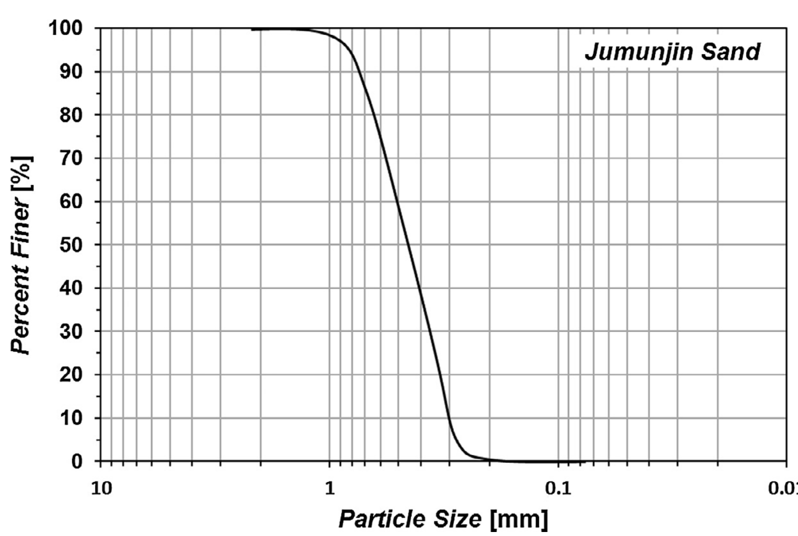

Fig. 1. Particle size distribution curve of jumunjin sand.