The 2023 World Congress on
Advances in Structural Engineering and Mechanics (ASEM23)
GECE, Seoul, Korea, August 16-18, 2023

Consolidation behavior of biopolymer-treated fine soil and possible application

*Dong-yeup Park[1)], Jeong-Uk Bang[2)], Minhyeong Lee[3)] ,
Ilhan Chang[4)] and Gye-Chun Cho[5)]

[1),2),5)] Department of Civil and Environmental Engineering, KAIST, Daejeon 34141, Korea
[3)] Disposal Performance Demonstration Research Division, KAERI, Daejeon 34057, Korea
[4)] Department of Civil Systems Engineering, Ajou University, Suwon-si, 16449, Korea

[1)] dypark2160@kaist.ac.kr [2)] jeonguk.bang@kaist.ac.kr [3)] leemh@kaeri.re.kr
[4)] ilhanchang@ajou.ac.kr [5)] gyechun@kaist.ac.kr

ABSTRACT

Geotechnical engineering practices have incorporated microbial biopolymers in response to the growing need for sustainable construction materials. Biopolymer treatment is making various attempts to utilize it as a hydraulic barrier such as levee and dam to respond to global climate change as well as sustainable development. Among them, xanthan gum was confirmed to increase various geotechnical properties such as uniaxial compressive strength and shear strength through soil treatment. However, xanthan gum has the disadvantage that strong particle bonding occurs through dehydration, and then loses strength in the submerged state. In order to compensate for this disadvantage, it was recently confirmed that the strength is expressed even in the submerged state when cation crosslinking (CrXG) is performed on xanthan gum. However, most of the studies related to xanthan gum performed experiments only on coarse sand, and there is a lack of understanding about fine soils such as clay. Therefore, in this study, the effect of improving swelling behavior and permeability was confirmed through a consolidation test to see the effect of CrXG-treated fine soil as a hydraulic barrier. This study demonstrates the possiblie application of controlling hydraulic conductivity by CrXG treatment.

1. INTRODUCTION

[1),2)] Graduate student
[3)] Researcher
[4)] Associate Professor
[5)] Professor

The construction of structures on soft clay ground poses significant challenges, mainly attributed to the consolidation settlement over extended periods. The cohesive nature of clay soil and its low permeability coefficient contribute to stability issues and hinder the timely drainage of pore water. This consolidation settlement in clay can be categorized into primary and secondary consolidation processes. Primary consolidation is associated with hydraulic retardation due to clay's permeability, compressibility, and drainage distance, while secondary consolidation occurs gradually under certain effective stress, characterized by a time-dependent increase in deformation. Secondary consolidation, in particular, presents considerable economic difficulties during construction and maintenance, both pre and post-construction, highlighting the pressing need for detailed research and theoretical establishment on the consolidation progress mechanism, especially concerning secondary consolidation, where a clear theory is yet to be established.

Recently, Crosslinked-Xanthan gum (CrXG) biopolymer has emerged as a promising solution, exhibiting enhanced wet strength compared to conventional Xanthan gum. This advancement offers potential for the application of biopolymer sand treatment (BPST) in water, as CrXG displayed superior uniaxial compressive and shear strength even under dynamic loading conditions. The strengthened performance of CrXG is attributed to the formation of a rigid gel through crosslinking Xanthan gum molecules, rendering it resilient in wet conditions. While the geotechnical improvements have been verified through strength tests on sandy soils, this study explores the consolidation behavior in clay ground using CrXG's rigid gel formation phenomenon. To accomplish this, bintang kaolinite, a representative clay type, was employed. Through a comprehensive evaluation of consolidation behavior characteristics, permeability, and consolidation coefficients, the study compares CrXG-treated kaolinite with untreated kaolinite, shedding light on the potential benefits of utilizing CrXG in improving the geotechnical performance of clayey terrains.

2. CONSOLIDATION TEST

2.1 Materials

2.1.1 Soil: Kaolinite

The present study utilized Bintang kaolinite sourced from Belitung Island, Indonesia, as the specimen for investigation. In accordance with the unified soil classification system (USCS), Bintang kaolinite is designated as highly plastic clay (CH), exhibiting a plastic limit of 24% and a liquid limit of 70%. The average specific surface area of the kaolinite, estimated through the methylene blue adsorption method, was determined to be 22 m^2/g. Particle size distribution analysis was conducted using a laser diffraction particle size analyzer (HELOS/KR-H2487) following the ASTM International standards D4464-15 and B822-20.

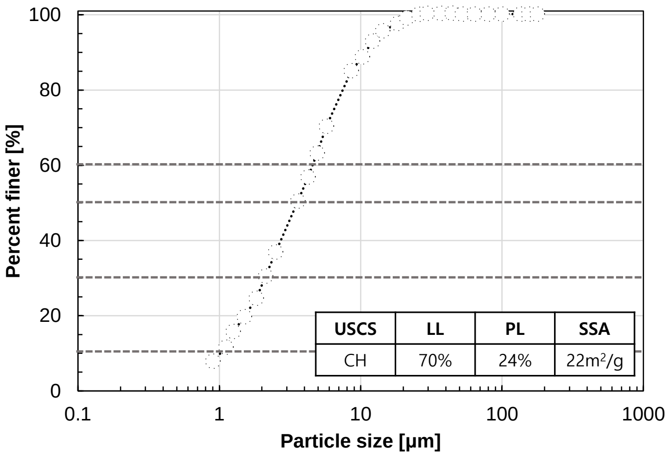


Fig. 1 Particle size distribution of Bintang Kaolinite

2.1.2 Biopolymer: Crosslinked Xanthan Gum

When xanthan gum hydrogel, possessing anionic properties on its surface, encounters an aqueous solution containing cations like Cr^{3+}, Ca^{2+}, Fe^{3+} the cations interact with the anions on the surface, leading to crosslinking and subsequent hardening of the hydrogel (see Fig. 2). In simpler terms, while the conventional xanthan gum-treated soil gains strength during the drying process as previously observed (Chang et al., 2015), the introduction of cations through crosslinking with xanthan gum enhances the strength of the soil progressively over time. For this particular study, Cr^{3+} ions were chosen among various cations. Consequently, the soil treated with xanthan gum and crosslinked with Cr^{3+} in this investigation is referred to as CrXG treated sand.

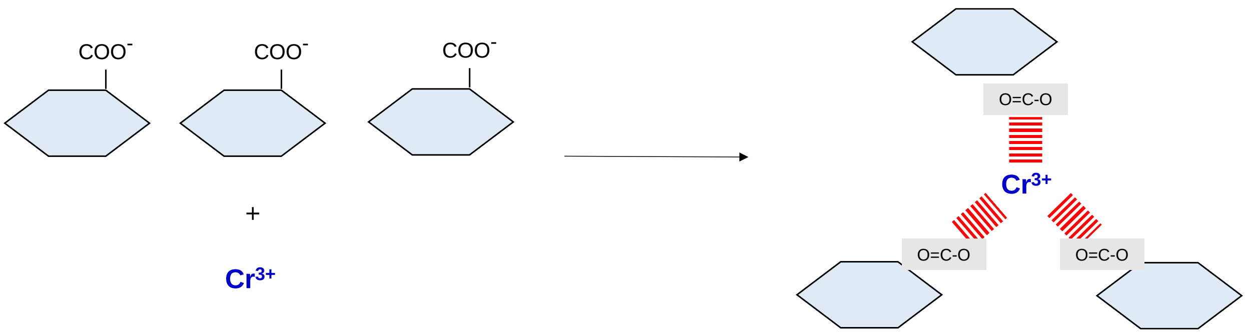


Figure. 2 Crosslinking of xanthan gum and Cr^{3+} ion

2.2 Experimental methods

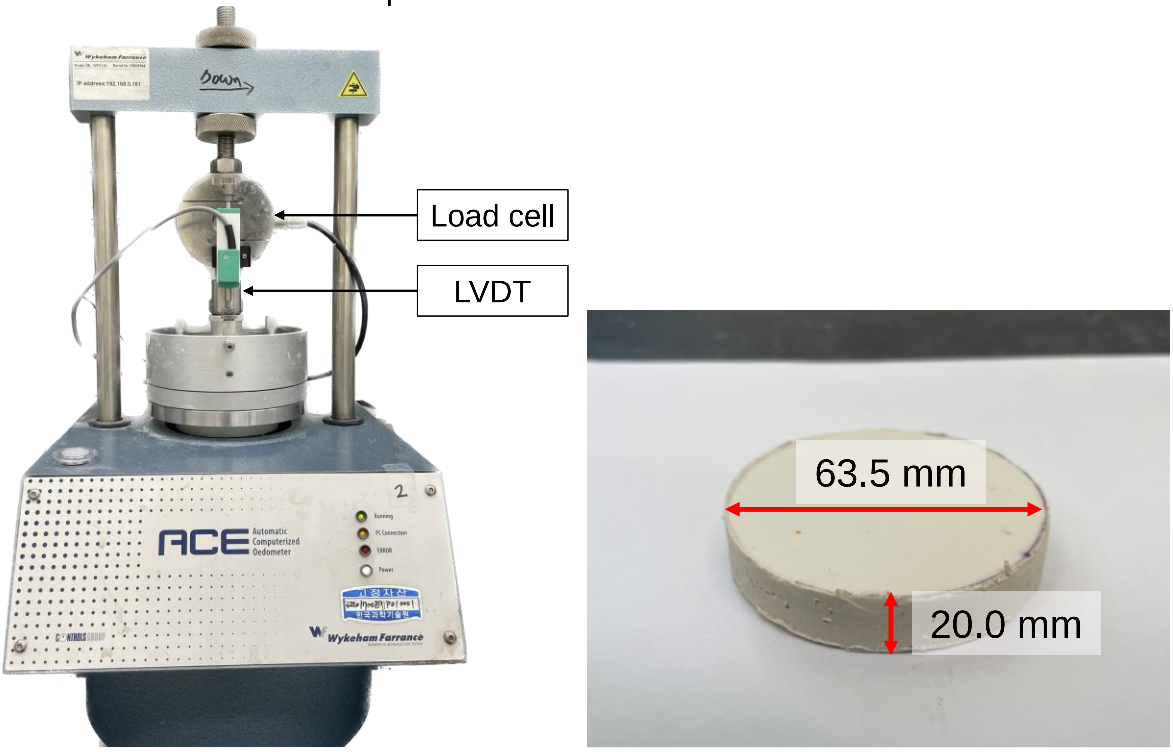
2.2.1 Consolidation test

It is important to understand the effects of the generation and dissipation of excess pore water pressure during consolidation loading on the compressive and secondary consolidation characteristics of kaolinite according to the loading period. The oedometer cell used in this study is a computerized consolidation test apparatus

(Wykeham Farrance; 26-WF3120). The diameter of the cell is 63.5 mm and the height is 74 mm, and the size of the specimen is 63.5 mm in diameter and 20 mm in height. The initial load started with 5 kPa, then 12 kPa, 25 kPa, 50 kPa, 100 kPa, 200 kPa, and 400 kPa were applied sequentially. After the maximum load was applied, 200 kPa, 100 kPa, and 50 The load was reduced in kPa. For all loading and unloading, consolidation was performed until the change in axial height was less than 0.01 mm for more than 24 hours. Consolidation data were analyzed based on the square-root-of-time (Taylor) method. The void ratio at the end of primary consolidation was determined based on the log-of-time (Casagrande) method.

2.2.2 Specimen preparation

The sample used in this study was kaolinite, and a sample dried for more than 24 hours in a dry oven of 100 degrees was used for purity. The water content ratio of CrXG-treated kaolinite was 80%, and after forming CrXG gel, it was thoroughly mixed with untreated kaolinite by hand-mixing. For CrXG gel, mix xanthan gum powder with an appropriate amount of water through a mixer for about 120 seconds, then mix with the trivalent chromium aqueous solution prepared elsewhere. Since the cross-linking between the chromium aqueous solution and the xanthan gum hydrogel occurs immediately after mixing, hand mixing with kaolinite is performed immediately after sufficient mixing has been achieved. Since crosslinking occurs over time, it is very important to keep a good record of the time between the sample being mixed and the start of the consolidation experiment.



(a) Oedometer apparatus (b) Specimen description

Figure. 3 Outline of consolidation test

3. RESULTS

In this study, experiments were conducted based on an automatic oedometer apparatus to see the consolidation behavior of CrXG treated kaolinite compared to untreated kaolinite specimens. The experimental results are shown in Figure 4. The value of the initial void ratio was about 1.9 for untreated kaolinite, which was higher than that of CrXG. In addition, while the settlement amount according to the effective vertical stress was moderate for CrXG, it was confirmed that the settlement occurred rapidly for untreated kaolinite. Calculating the value of the consolidation coefficient by the change in the void ratio according to the increase in the effective vertical stress, it can be confirmed that CrXG is 0.29 and untreated kaolinite is 0.53. The higher the value of the consolidation coefficient, the higher the possibility of future settlement of the soil and the higher the possibility of long-term settlement. Through the results, it can be confirmed that sedimentation is prevented when CrXG is treated with kaolinite.

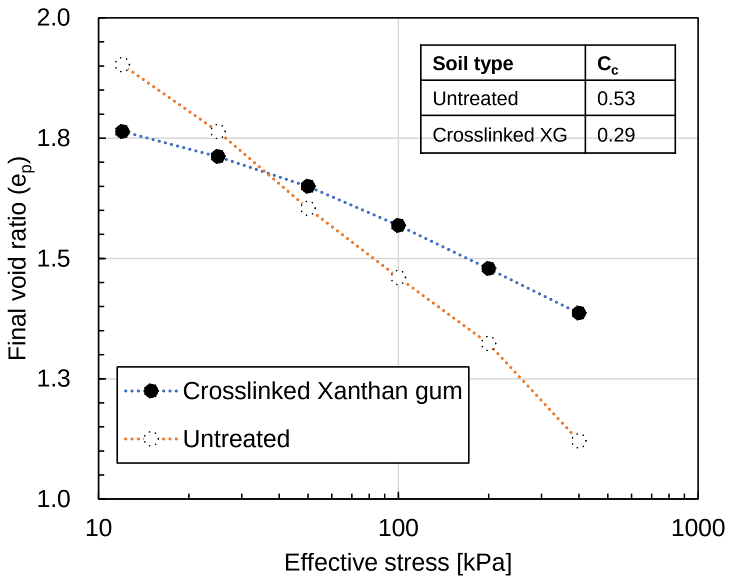


Figure 4. Cyclic resistance ratio (Jumunjin sand, Gellan gum, Xanthan gum)

4. CONCLUSIONS

In this study, a consolidation test was performed to see the effect of kaolinite, a type of soil with high compressibility, on the biopolymer. As expected, kaolinite with high compressibility had a high consolidation coefficient value, whereas kaolinite treated with crosslinked Xanthan gum had a consolidation coefficient value of 60% compared to untreated kaolinite. It is confirmed that the binders combined with kaolinite are effective in preventing settlement during biopolymer treatment. It is considered that additional experiments with various recipes are necessary for more accurate results. Through this study, it was confirmed that crosslinked Xanthan gum is effective in preventing subsidence in clay ground, and it is expected to help form stabilized ground if applied in a ground with high clay content and prone to subsidence.

ACKNOWLEDGEMENT

This work is financially supported by Korea Ministry of Land, Infrastructure and Transport(MOLIT) as 「Innovative Talent Education Program for Smart City」

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government. (MSIT) (2023R1A2C300559611)

REFERENCES

Kwon, Y. M., Chang, I., & Cho, G. C. (2023). Consolidation and swelling behavior of kaolinite clay containing xanthan gum biopolymer. *Acta Geotechnica*, 1-17.

Kwon, Y. M., Chang, I., & Cho, G. C. (2023). Xanthan biopolymer-based soil treatment effect on kaolinite clay fabric and structure using XRD analysis. *Scientific Reports*, *13*(1), 11666.

Lee1a, M., Im1b, J., Chang2c, I., & Cho, G. C. (2021). Evaluation of injection capabilities of a biopolymer-based grout material.