学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Beachrock formation mechanism and its application to developing beach sand cementation method based on microbial induced carbonate precipitation (MICP): Case study of Krakal-Sadranan, Yogyakarta, Indonesia

(ビーチロック形成機構と微生物による炭酸塩析出に基づく海浜砂セメンテーション法の開発への応用:クラカル-サドラナン (ジョグジャカルタ, インドネシア) における事例研究)

The aim of this dissertation is to assess the feasibility of exploiting ureolytic microbial adjustment activity in carbonate precipitation as a unique and novel grout, developing a countermeasure for coastal erosion using biochemical methods to improve the ground. Conducting research on the impact of direct morphology and erosional processes on in pristine or reference beachrock toward could provide essential information on the natural mechanism of the sediment and the function of microbial control in the carbonate. Microbial induced carbonate precipitation (MICP) is an effective and eco-friendly technology that can be applied to solve various environmental problems. Biominerals including calcium carbonate or calcium phosphate are involved in production of complex multifunctional composites with organic macromolecules. It is highly important to explore the multiple functionality of MICP and upscale its implementation in different areas to fully realize its potential as a versatile technique for soil improvement applications. This research framework was used to study the biological, geophysical, and engineering aspects that could deepen the understanding of MICP technology and push it closer towards field implementation.

Chapter 1 describes the research background, objectives, and originality of this thesis. A comprehensive literature review is conducted relate to various aspects of natural beachrock processes and the stability of the MICP process.

Chapter 2 presents a geophysical investigation of buried beachrock at Krakal-Sadranan beach, Yogyakarta, Indonesia. The objective of the investigation was to evaluate the feasibility of constructing artificial beachrock using natural materials (e.g., microbes, sand, shell, pieces of coral, and seaweed) within a short time, and to propose a method to use this for coastal protection. A field survey on natural beachrock suggests that both resistivity and shear wave velocity were higher in deep deposits than in the underlying unconsolidated sand layer within a depth of approximately 1.5 m, and that this covered an area of 210.5 m^3 for the α-section and 76.9 m^3 for the β-section of the beachrock deposit.

Chapter 3 presents a detailed laboratory analysis of the investigation of the characteristics of beachrock sediment. Beachrock was also examined to determine the depositional conditions and distribution of rare earth elements therein. An increased concentration of both heavy rare earth elements (terbium, dysprosium, yttrium, holmium, erbium, thulium, ytterbium, and lutetium) and light rare earth elements (lanthanum, cerium, praseodymium, neodymium, samarium, europium, and gadolinium) suggests that the beachrock deposition process occurred under oxidative environmental conditions. This study proposes a novel use of ureolytic bacteria in a depositional environment to control the carbonate in a sedimentary process to develop artificial rock with which to mitigate coastal erosion. The resulting bacterial strains are highly homologous to the 16S rRNA nucleotide sequence of the species *Oceanobacillus profundus*, *Vibrio maritimus*, and *Pseudoalteromonas tetradonis*.

Chapter 4 describes the culturing of ureolytic bacteria from the Indonesian tropical shoreline, that was compared with that from the characteristic beachrock in Okinawa, Japan. Okinawa beachrock was classified as a biotically induced precipitate because an organism set the precipitation process in motion, although the latter then has a marginal or absent organic influence. However, Indonesian beachrock is classified as a biotically controlled precipitate, meaning that it is commonly precipitated by microorganisms, mostly bacteria and cyanobacteria.

Chapter 5 described a beach sand treatment based on the MICP process; it produced a result that mimicked the natural beachrock based on chemical compound and strength. The results revealed that the bacteria could effectively mineralize calcium carbonate between 30 ℃ and 40 ℃, showing a more robust performance under tropical conditions. The effects of various chemical compositions were also critically investigated to deepen the understanding of the biochemical processes involved. The results of the sand solidification test in the laboratory showed that treated sand achieved an unconfined compressive strength of up to approximately 6 MPa after a treatment period of 14 days under optimum conditions. By adding biopolymer polysaccharides, the reaction leads to crystal formation of vaterite instead of calcite. The calcium carbonate crystals studied in this research were found to be orthorhombic, rhombohedral, hexagonal, and spherical geometries.

Chapter 6 discusses the testing of durability of this material based on MICP for in the development of a countermeasure for coastal disasters. An experiment was performed to investigate the effects of environmental parameters on its long-term performance. As the tropical regions experience frequent rainfall, wetting-drying tests were performed as a potential indicator of durability. The results showed that there was significant wetting-drying damage and that this would have the foremost effect on the long-term performance of the MICP beach slope.

Chapter 7 suggests cost reduction purposes using cheap chemical reagents from cultured media and cement solution for MICP treatment. The aim of that study was to determine the feasibility of cultivating a strain of *P.tetradonis* in an economical food-grade yeast extract (beer yeast and tempeh starter) medium and investigate its effect on bacterial production, urease activity, and biocalcification.

Chapter 8 outlines the proposal for a coastal prevention method in Indonesia based on ureolytic bacteria. The results obtained from this study are used to summarize the application guidelines for the optimal chemical compositions, suitable environmental conditions, and ways to monitor the process.

Chapter 9 summarizes and provides a conclusion that may guide future work. In summary, I have used biomechanics as a countermeasure against coastal erosion and other problems considering the potential use of a biocementation MICP treatment to develop a shoreline or beach slope. This will provide new knowledge about biotechnology and will greatly contribute to the development of environmental resource engineering.