別紙様式第２号 Form2
(都市イノベーション学府 Graduate School of Urban Innovation)

# 論 文 要 旨

## Summary of Dissertation

令和　2024　年　08　月 26　　日
Date (YYYY-MM-DD):

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| 専　　攻<br>Department | Department of Urban Innovation |
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| 論文題目<br>Title | Influence of Stabilizer Types and Aeration Conditions on $CO_2$ Capture in Alkaline Construction Sludge During pH Neutralization |
| 和訳または英訳<br>Translation (J->E, or E->J) | **アルカリ建設汚泥の中性化における二酸化炭素固定への改質材の種類と通気条件 の影響** |


This study focuses to investigate the impact of the types of stabilizers used and the aeration conditions of carbon dioxide on the carbon dioxide capture in soil during neutralization in construction sludge treatment. All over the world, there was due to the increasing number of vehicles and industries, the temperature was increased. Especially, in Japan, the recorded temperature in 2023 was the highest. There is a growing need in civil engineering to develop solutions that are both economical and deliver the smallest carbon footprint possible and are sustainable. An overview of the importance in production and creating towards more sustainable geotechnical technologies, the challenges and opportunities in continued advancement. In addition, in response to the Paris Agreement, the Ministry of Economy, Trade and Industry decided on the ``Fifth Energy Plan'' in 2020, aiming to reduce greenhouse gas emissions by 26% by 2030 compared to 2013. Therefore, in the geotechnical field, carbon dioxide fixation associated with the neutralization of alkali soils is considered. It expected in the further, will be developed and applied to contribute to the reduction in carbon dioxide emission. The previous researchers have not investigated extensively about the amount of carbon dioxide used to neutralize alkali soils treated with industrial byproduct-based stabilizers.

In this study, Ao clay and six types of stabilizers such as, quicklime powder (QL), blast furnace cement type B (BFCB), paper sludge ash-based stabilizer (PSAS), fly ash-based stabilizer (FA), blast furnace slag (BFS) and palm kernel shell ash (PKSA) are used to reduce the environmental impact and cost beneficial for the engineering applications. Carbon dioxide incubator was used for carbon dioxide curing. Calcium carbonate evaluation test was conducted. Hydrochloric acid was used. Novel testing method, column tests are performed for carbon dioxide curing. The alkalinity value of soil samples before and after neutralization were investigated. The amount of reduction of pH due to the completion of pH neutralization and $pH^{initial} - pH^{final}$, increased with $C_{CaO}$. It became clear that there is a relationship between calcium oxide content and carbon dioxide curing period. The maximum fixed $CO_2$ content per gram of dry mass of soil, $(m_{CO2})^{max}$, increased with the CaO content of the stabilizer(s) per gram of dry soil, $C_{CaO}$. However, the rate of increase was significantly affected by the type of stabilizer used. In general, the maximum amount of $CO_2$ fixed per gram of dry mass of stabilizer(s), $(m^*_{CO2})^{max}$, increased with the CaO content per gram of stabilizer(s) in the alkali soil, $C^*_{CaO}$. The results reveal that the calcium oxide content and the amount added of the stabilizer influence the amount of carbon dioxide fixed in the soil.

In addition, this study also aims to evaluate the effects of carbon dioxide aeration conditions and soil conditions on the carbon dioxide fixed in the soil during neutralization. The ventilation period required for the

completion of $CO_2$ fixation ($t_{EOF}$) was estimated from each column test result. $t_{EOF}$ increased with an increase in the dry density ($\rho_d$) or specimen height ($H$). This was because a higher density and larger volume of the specimen consumed more $CO_2$ gas for pH neutralization. Meanwhile, ($t_{EOF}$) reduced with the increase in the $CO_2$ gas concentration, $C$ or flow volume of the $CO_2$ gas, $Q$. This was because when $CO_2$ gas concentration, $C$ or flow volume of the $CO_2$ gas, $Q$ was low, the supply of $CO_2$ gas that could be dissolved in the water might not keep up with the consumption induced by the reaction. The maximum amount of $CO_2$ fixed per gram of dry soil ($(m_{CO2})^{max}$) was determined from the $CO_2$ inflow and outflow for each test specimen. Lower values of $C$ and $Q$ tended to result in higher $(m_{CO2})^{max}$, whereas higher values of $\rho_d$ and $H$ resulted in higher $(m_{CO2})^{max}$. Additionally, $(m_{CO2})^{max}$ increased with increasing $t_{EOF}$, although pH decreased slightly after neutralization with increasing $t_{EOF}$. This suggests that it may be difficult to accurately evaluate the amount of $CO_2$ fixation simply by checking pH. It was also demonstrated that thicker soil layers and higher densities prolong the neutralization process, thereby slowing down carbon dioxide fixation, whereas higher flow rates and concentrations of carbon dioxide accelerate the fixation. Finally, based on the findings, attempts were made to assess the material-based $CO_2$ emissions of neutralized recycled construction sludge and efficient $CO_2$ aeration method for production. By considering the $CO_2$ capturing amount in the pH neutralization process, the neutralized recycled construction sludge can be carbon negative on the material basics. For the constant flow rate condition, higher flow rate results in faster $t_{EOF}$, however, carbon dioxide consumption rate, *CSR* (%) becomes lower. The low *CSR* (%) means that the amount of unused $CO_2$ gas is high for pH neutralization process. To solve this condition, the step-wise changed the flow rate during the $CO_2$ curing. This method increased the *CSR* (%) without increase the $t_{EOF}$. Furthermore, it proposes that by adjusting the flow rate in stages, the amount of carbon dioxide that does not contribute to neutralization can be reduced, and the fixation can be efficiently advanced.

This research is anticipated to contribute to organizational studies in considering several factors affecting carbon dioxide fixation behaviors associated with the neutralization of alkaline construction sludge towards environmental sustainability. Although the amount of the carbon dioxide fixation per unit mass is less, it can be expected the field of civil engineering should contribute to the decarbonization policy promoted in all countries of the world. It is also expected, however, numerous opportunities that may produce even more sustainable solutions have yet to be identified. In this study, we conducted the experiments using carbon dioxide, a commercially available byproduct of petroleum refining. It is expected that this research will add, enrich, and contribute to literature. From this study, consequently, it can be proposed that by adjusting the flow rates in midway through the carbon dioxide aeration, the amount of carbon dioxide that did not contribute to neutralization can be reduced and the fixation can be efficiently carried out. According to the findings from this study, lower carbon dioxide concentrations resulted in a longer carbon dioxide aeration conditions; however, by controlling the soil density, soil layer thickness, and flow rate can potentially shorten the carbon dioxide aeration period. Evaluating the pH value only based on the calculation of carbon dioxide fixation was difficult to qualify the requirements. Therefore, it should be considered not only the calcium contents in recycled soil but also other chemical components that included in alkali soils. For further studies, hydraulic conductivity test and swell tests with carbon dioxide aeration should be considered to find out the carbon dioxide aeration period and to estimate the $(m_{CO2})^{max}$. In the future, recycled soil production plants are expected to use carbon dioxide emitted from the factories or carbon dioxide fixation from the atmosphere to reduce the manufacturing costs of recycled soil. The carbon dioxide concentration is expected to vary depending on the supply source. It should be established the effective utilization of recycling soils, to develop the technology and to promote from the government, institutional organizations and stakeholders.

4,000 字以内 Must not exceed 4,000 Japanese characters or 1,600 words.

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The English title of the dissertation should be written in sentence case, where only the first letter of the first word is capitalized. It should not exceed 250 characters in English (single-byte characters) and 125 characters in Japanese (double-byte characters). Special characters such as umlauts or accent marks are not permitted.