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論文審査の要旨

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論　文　題　目

IMPACT OF VARIOUS CHLORIDE SOLUTIONS ON THE LEACHING CAPACITY AND ADSORPTION/DESORPTION CHARACTERISTICS OF HEAVY METALS IN CEMENT-BASED MATERIALS

(各種塩化物溶液がセメント系材料中の重金属の溶出能力および吸脱着特性に与える影響)

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〔論文審査の要旨〕

The construction industry has significantly contributed to carbon dioxide emissions and resource depletion. Promoting sustainable development within the construction sector is crucial for mitigating its environmental footprint. In response, many cities are now using urban waste, industrial by-products, and construction and demolition waste as alternative materials for concrete. However, these additives often lead to substantial leaching of heavy metals. Limited prior research has addressed the leaching of heavy metals from concrete in chloride environments, particularly regarding how chloride influences the immobilization and leaching of heavy metals from cement hydrates. This study aims to assess the long-term leaching of Cu, Zn, and Pb from mortars exposed to various chloride solutions as well as to investigate the adsorption behavior of Pb on cement hydrate and C-S-H under these conditions. The study also aims to explore how variations in pH impact Pb's adsorption characteristics in these chloride environments.

To achieve the objectives above, the structure of this thesis is arranged as follows:

Chapter 1 introduces the background, objectives, and methodology of this study.

Chapter 2 presents a literature review on the content of heavy metals in cementitious materials, the mechanisms of heavy metal fixation, and the impact of environmental factors, such as pH and chlorides, on heavy metal leaching. This chapter also discusses various leaching tests for assessing the safety of heavy metals in cement-based materials.

Chapter 3 describes the experimental program to study the leaching and adsorption behavior of heavy metals in cement-based materials under various chloride environments. The experiments start by preparing mortar specimens with two different water-to-cement ratios (0.40 and 0.55) using ordinary Portland cement. The focus is on three heavy metals: Cu, Zn, and Pb, chosen due to their

prevalence in supplementary cementitious materials and recycled aggregates. These metals are introduced into the cement mixtures in nitrate form at a 1% ratio by mass relative to the cement. The specimens are subjected to a tank leaching test using 10% NaCl, KCl, $MgCl_2$, and $CaCl_2$ solutions and deionized water. The leaching behavior of heavy metals from these specimens is monitored for 625 days. The chapter also delves into the adsorption characteristics of Pb on cement paste and C-S-H through adsorption tests using various chloride solutions. The study examines the impact of pH on Pb adsorption by altering the liquid-to-solid ratio and using nitric acid.

Chapter 4 delves into the impact of chloride-based salts on the leaching and immobilization of Cu, Zn, and Pb in cement hydrates. Observations indicated that leaching was highest in the presence of $CaCl_2$, significantly exceeding the leaching levels observed with other chloride solutions and in deionized water. This finding underscores the unique role of $CaCl_2$ in enhancing heavy metal leaching from cement-based materials. The chapter also explores how these chloride solutions influence the internal crystalline structure of the cement hydrates. It was found that exposure to $MgCl_2$ led to the transformation of portlandite into brucite, resulting in a reduction in pH and consequently in the leachate quantities of Cu, Zn, and Pb. Additionally, EPMA results revealed that in the case of KCl solutions, the weaker binding capacity of chloride ions compared to $CaCl_2$ may explain the lower leaching of Pb. These findings underscore the significant and varied influences of chloride solutions on the long-term leaching behavior of heavy metals from cement-based materials.

Chapter 5 centers on the influence of various chloride solutions on the adsorption and desorption properties of Pb in hardened cement and C-S-H. Key findings reveal that the adsorption behavior of Pb is significantly impacted by the type of chloride solution used. Among the tested solutions, $MgCl_2$ showed the highest Pb adsorption, while $CaCl_2$ resulted in the lowest. This indicates that different chloride solutions can alter the adsorption capacity of cement hydrates for heavy metals. The study further highlights the effect of pH on Pb adsorption, noting an increase in adsorption as the pH shifts from alkaline to neutral. This trend, however, is not evident in the presence of chlorides, suggesting other influencing factors beyond pH. In the case of C-S-H, the adsorption characteristics differed based on the Ca/Si ratio and the chloride solution used. The study confirms that lower Pb adsorption on C-S-H correlates with higher leachate quantities in chloride solutions. It was also found that $CaCl_2$ plays a role in retaining calcium in C-S-H, affecting Pb adsorption.

Chapter 6 describes the conclusions of this study and makes recommendations for future work.

The examining committee evaluated that the dissertation met the standard of excellence expected of a doctoral candidate at Hiroshima University.

備考：審査の要旨は，1,500 字以内とする。