学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Immobilization of Heavy Metals by Metakaolin-Based K-Geopolymer
(メタカオリンを用いたカリウム型ジオポリマーによる重金属の不溶化)

Liquid and solid waste from anthropogenic activities commonly contain heavy metals, such as mercury, cadmium, lead, and zinc. These metals exist in wastes in various concentrations and combinations. Exposure to these metals can cause damage to the nervous and reproductive systems, skeleton, liver, kidneys, cardiovascular and respiratory systems. Due to their high toxicity, environmental contamination caused by heavy metals from waste has become a concern. The contamination may occur from the direct disposal of industrial wastes, such as sludge and fly ash, in landfills. Heavy metals may undergo desorption from the sludge. These metals can also leach out from fly ash due to their presence as soluble chloride or sulfate salt. Aside from the common industrial activities, fly ash is also produced from the municipal solid waste incineration of the Fukushima Dai-Ichi Nuclear Power Plant. This waste contains not only heavy metals but also radioactive cesium. Consequently, an appropriate treatment to stabilize a wide variety of wastes containing heavy metals is needed. One of the potential binders for solidification/stabilization treatment is geopolymer. Studies have shown the excellency of sodium-activated geopolymer to immobilize metal cations. However, each study concluded different kinds of immobilization mechanisms within a particular metal due to the variety of use of aluminosilicate precursor, metal concentration, and mixing procedure. Therefore, clarification of the mechanisms is needed to predict their long-term stability. The long-term stability can also be expected with the use of potassium-activated geopolymer instead of sodium. Despite its prominent advantages, potassium-activated geopolymer is less studied. This dissertation explores the use of potassium-activated geopolymer to immobilize heavy metals. This research aims to understand heavy metals immobilization mechanisms to propose geopolymer use in stabilizing contaminated wastes.

Chapter 1 of the dissertation provides a comprehensive background for this study. It introduces the potential of geopolymers, particularly potassium-activated ones, in immobilizing heavy metals. The chapter concludes with the study objectives.

Chapter 2 presents a literature review on geopolymer, including its component and formation process. This chapter also summarizes previous studies on heavy metals immobilization using this material.

Chapter 3 investigates the effect of mixing procedure and heavy metal concentration on cadmium and mercury speciation in potassium-activated geopolymer. This chapter suggests that the mixing procedure can control their final speciation and geopolymer characteristics. This chapter also shows the difference of mercury immobilization in various concentrations and highlights the applicability of geopolymer to manage waste of various cadmium concentrations.

Chapter 4 elucidates the immobilization mechanisms of zinc, cadmium, mercury, and lead in potassium-activated geopolymer through the use of various analytical instruments. Factors affecting

the mechanisms, including their similarities and differences, are also explained.

Chapter 5 focuses on immobilizing mercury in potassium-activated geopolymer. This chapter shows the success of using hydrosulfide as an additive. This chapter also highlights the effect of different methods and mercury-to-sulfur ratios on immobilization.

Chapter 6 shows the effect of hydrosulfide addition on the immobilization of other metals, namely zinc, cadmium, and lead, by observing their leaching behavior in deionized water. The chapter reveals that hydrosulfide addition brings a positive effect on immobilization.

Finally, Chapter 7 provides a summary and general conclusion of the study, highlighting the findings and implications as well as suggesting directions for future research.