



HOKKAIDO UNIVERSITY

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学 位 論 文 内 容 の 要 旨

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Experimental Investigation of the Deformational Behavior of the Phases of Concrete During Freezing and Thawing Cycles

(凍結融解繰返し作用下のコンクリートの各相の変形挙動に関する実験的研究)

This study presents the diverse experimental methods and results on the deformational behavior of the phases of concrete (mortar, aggregate and interfacial transition zone - ITZ) in meso-scale during freeze-thaw cycle (FTC). The FTC damage in concrete has long been a durability related problem in cold region like here in Hokkaido. This is why there is a large volume of research to clarify and understand the frost damage in concrete. However in spite of the large volume of research there are no consensus on the damage mechanism of concrete due primarily to concrete's heterogeneous characteristics and the complex behavior of moisture during FTC. With this regard, it is the purpose of this study to present the deformational behavior of the constituent part of concrete (mortar, aggregate and ITZ) which is believed to be distinct from each of the other to clarify each of their role during FTC and the overall deformation of concrete.

Unlike the common methodology in frost damage in concrete, specimens were sealed in the experiment so that moisture and temperature can be controlled. In addition, meso-scale size specimens are used in this study. The meso-scale size can be used to simulate the frost actions in a specific (localized) location of a bulk sample with conditions similar with the data used. Specimens were subjected to FTC under different moisture conditions. The increase in void ratio and decrease in elastic modulus associated with frost damage have been investigated and are related to the CTE change of frost damaged specimens. The study also investigates the deformational behavior of the ITZ which have not been presented in the microstructural investigation of concrete. The behavior of aggregate during FTC has been investigated as well.

Based on the experimental results, the findings indicate that the deformational behavior of the specimens under FTC is primarily dependent on the amount of its moisture. The larger the amount of moisture, the larger will be the resulting deformation in both expansion and contraction behavior. The expansion during FTC is understood and pointed to be caused by the hydraulic pressure caused by ice formation during FTC. The contraction phenomena is also observed prior to the expansion. Due to constant moisture content, a limitation in the increase in tensile strain is observed during FTC and this tensile strain decreases until contraction is observed. The contraction is attributed to the removal of gel pore water arising from negative pressures. With an increased pore volume (void ratio) due to microcracks arising from frost damage and more importantly absence of available water supply, the specimens becomes partially saturated and the displaced pore water cannot be refilled, thus the sample cannot re-expand and results in contraction at the end of the FTC.

After FTC tests, results show that the CTE of frost damaged mortar increases and its elastic modulus

decreases which are primarily caused by microcracking when frost damage takes place. The reduction in elastic modulus has been related to the increase in void ratio which represents the formation of microcracks of frost damaged specimens. Microcracks act as broken bridges or links which can detach the aggregate from the hardened cement paste and in effect reduces (or removes) the thermal restraints that fine aggregate and cement paste exerts on the other. The hardened cement paste can then expand or contract more freely under temperature variation, and thus can significantly affect (increase) the CTE of the whole composite (mortar). The stress transfer in the material is prevented as well due to microcracking resulting in elastic modulus reduction.

On the one hand, the aggregates did not indicate considerable permanent deformation during the whole FTC though the specimens were conditioned to be fully saturated. This verifies the common acceptable knowledge that aggregate are unaffected by frost damage. The ITZ deformation is determined as distinct (being far higher) from the mortar and aggregate which is the crucial reason why the ITZ is treated as a separate phase in concrete. Besides its weaker strength, the much higher deformation of the ITZ during FTC where cracking and prominent damage are initiated and could extend to the matrix shows the important role of the ITZ during frost damage and other factors such as wet dry cycles (WDC).

The obtained deformational behavior of the ITZ, mortar, and aggregate in this investigation reflects their commonly described behavior during FTC. The ITZ and mortar deformation agrees well with the observations on the occurrence of cracks for frost-damaged specimens and non-occurrence of cracks for dry specimens. These indicate the reliability of the presented method and suggest that the experimental method can be used as a basis to obtain the deformational behavior of mortar, aggregate and ITZ during FTC. Significantly, the results presented here are first and a complete data on the deformational behavior of mortar, aggregate, and ITZ have not yet been presented. The results and methodology presented in this study is therefore important in clarifying, understanding and simulation of frost damage in concrete.