DEVELOPMENT AND PERFORMANCE OF SELF-HEALING AND SELF-IMMUNE SOIL-CEMENT SYSTEMS SUBJECTED TO FREEZE-THAW CYCLES

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ABSTRACT

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Soil-cement systems are used in a wide variety of engineering projects. However, soil-cement systems are vulnerable to cyclic freeze-thaw deterioration. The engineering properties of soil-cement systems, such as strength and permeability, can be substantially degraded under the action of freeze-thaw cycles. This durability problem substantially impairs the sustainability of soil-cement systems and raises their maintenance and repair costs. Thus, when subjected to freeze-thaw cycles, civil infrastructure projects that use soil-cement systems can suffer from decreased reliability. Although extensive research has been carried out to improve the freeze-thaw durability of soil-cement systems, no method associated with significant improvement has been developed thus far.

Biological systems have recently provided inspiration for scholarly attempts to develop smart materials that comprise sustainable and resilient systems, which similarly can continually adapt and respond to their environment. Most of these efforts so far have focused on self-healing properties in polymers and concrete, and many of them have shown promising results. However, to date there has been very little work reported on the development of effective smart systems for geotechnical applications and there is very little literature focusing on the specific damage scenario caused by freeze-thaw cycles. Those systems (and their geotechnical applications) pose challenging problems that are distinct from those of, for instance, concrete. For this reason, they require a complete reimagining of how such smart systems ought to be designed. Therefore, the focus of this PhD project is on the development and performance of self-healing and self-immune soil-cement systems that can respond and adapt to freeze-thaw cycles.

Two different materials, microcapsules (produced by Lambson, UK) and LUVOMAG MgO pellets (produced by Lehmann & Voss, Germany), were used to develop self-healing soil-cement systems, and their self-healing capability was investigated. It was found that the addition of Lambson microcapsules improved the self-healing capability of soil-cement systems considerably in terms of unconfined compressive strength (UCS). The addition of MgO pellets not only substantially improved the self-healing capability of soil-cement

systems in UCS, but also showed great potential in terms of crack sealing. The microstructure investigations revealed that brucite and different types of hydrated magnesium carbonates, such as hydromagnesite and dypingite, were produced in the self-healed MgO pellet-embedded soil-cement samples after freeze-thaw cycles.

Biological systems, provided insights that aided the development of a self-immune soil-cement system. This is a system that can protect itself from cyclic freeze-thaw action before damage is initiated, thus preventing the occurrence of the damage, partially or entirely. A special admixture, SikaAer® Solid air entraining microcapsules was introduced to develop such systems. These uniformly distributed small compressible microcapsules can serve as pressure vessels by buffering the excess pressure generated during water freezing. Although initial dry density and strength properties generally decreased with the addition of the microcapsules, the final results demonstrate that the freeze-thaw resistance of soil-cement systems was substantially improved. Based on the results of the physical properties of soil-cement systems after freeze-thaw cycles, the microscopic analysis and the high resolution X-ray computed microtomography, the self-immune mechanism of soil-cement with SikaAer® Solid microcapsules and its behaviour during freeze-thaw action was revealed.

A superabsorbent polymer (BASF SAP A) was also used to develop self-immune soil-cement systems. Compared to SikaAer® Solid microcapsules, the addition of SAPs had little effect on the initial dry density, strength properties, and permeability of the soil-cement mixes, and the self-immune mechanism was slightly different. SAPs can absorb water during the mixing of soil-cement and they have the ability to release the absorbed water during the hydration and hardening processes. As a result, small cavities are created in the soil-cement system as the water within SAPs is donated for cement hydration. These uniformly distributed small pores can serve as small reservoirs and pressure vessels for water to enter and expand within the soil-cement matrix during the freeze-thaw process. This quality is captured in the results of the experiments, which demonstrated that the freeze-thaw resistance can be substantially improved by the addition of SAPs.

Overall, the self-healing and self-immune systems developed in this study showed promising results in terms of improving the self-healing and self-immune capability of soil-cement systems subjected to freeze-thaw cycles. More broadly, these smart systems contribute to attempts to build more resilient and sustainable soil-cement systems that may undergo freeze-thaw deterioration in the engineering practice.