

THESIS TITLE: THE ROLE OF EXPANSIVE MINERALS IN THE AUTOGENOUS AND AUTONOMIC SELF-HEALING OF CEMENT BASED MATERIALS

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Abstract:

Portland Cement (PC) based concrete has been popular in construction for over a century, yet concrete structures such as dams, roads, bridges and tunnels require considerable repair and maintenance during their service lifespan. The adoption of self-healing technology, which improves concrete's recovery after limited damage has been sustained, has the potential to address these challenges.

PC has a natural limited self-healing capacity triggered by the proportion of cement which remains unhydrated in the matrix and subsequently hydrates when it cracks. This is known as autogenous self-healing, and recent research has aimed to improve this autogenous self-healing capacity through restricting crack growth and/or through the use of expansive minerals based on calcium sulfoaluminate, blast furnace slag, Fly ash, and silica fume; minerals such as free lime and bentonite, which support healing, have also been used. However, the effectiveness of autogenous self-healing has hitherto been restricted to smaller healable crack widths, longer healing periods and the percentage of strength recovery. To overcome these challenges, autonomic self-healing techniques incorporating non-traditional concrete materials, such as capsules and vascular systems with healing agents, are being developed to further improve the healing performance. Popular autonomic healing agents are epoxies, cyanoacrylates, methyl methacrylate, alkali-silica solutions and microorganisms. However, these materials have concrete compatibility issues, health and safety concerns, and are associated with higher costs.

This research investigates the autogenous and autonomic self-healing capacity of cement based materials using the compatible expansive minerals MgO, bentonite, and quicklime. These three minerals were hypothesised to produce enhanced and efficient healing compounds. Therefore, in the first part of this thesis, a thorough investigation of the autogenous self-healing of PC cement was conducted by substituting different proportions of expansive minerals. Findings from this preliminary work suggest that these minerals improve load recovery, crack sealing and the durability performance of PC-mineral mixes at early age samples (1 day). Efficient healing was found for cracks smaller than 150 μm . Self-healing performances were found to reduce with the age of the samples. Nonetheless, mineral combination mixes resulted in a better self-healing performance over all ages. Finally, these results led to optimum mix proportions for efficient self-healing performance.

The autogenous self-healing capabilities of PC with expansive minerals were additionally investigated in terms of drying shrinkage crack healing. Cracks were induced in the samples with restraining end prisms through natural drying shrinkage over 28 days after casting. Cracks up to 500 μm were sealed in mineral containing samples after 28 days healing. Mechanical strength and

durability also improved with time. Microstructural investigations revealed highly expansive Mg-rich hydro-carbonate bridges along with traditional calcium-based self-healing compounds (calcite, portlandite, calcium silicate hydrates and ettringite). Overall, the optimised mix proportions of minerals resulted in the best healing performance.

Although the direct addition of the expansive minerals to PC improved its autogenous self-healing capacity, the release of unhydrated minerals from autonomic encapsulation systems can further enhance the healing efficiency. Hence, the final study includes the encapsulation of expansive powder and liquid minerals for the self-healing of cement-based mortars. In this study, liquid minerals (sodium silicate, colloidal silica, and tetraethyl orthosilicate) were encapsulated in parallel glass capsules, and a system of concentric glass macrocapsules was used to envelop the powder minerals (outer capsule) and water (inner capsule). The overall test was performed in three different curing regimes: ambient, high humidity and immersed in water. Immersed in water yielded optimum healing with over ~95% crack sealing and ~25% strength recovery in 28 days and a trend of further improvement over 56 days. Improvement in terms of gas permeability and capillary absorption of the healed samples was also significant after healing. The self-healing kinetics revealed that expansive minerals initially hydrated then slowly produced carbonated and even complex products over time until the crack zone became adequately watertight.

In summary, the expansive minerals used to enhance the autogenous self-healing capacity of cementitious materials for mechanically induced and drying shrinkage cracks and the efficient dispersion of liquid and powder minerals from autonomic encapsulation systems considerably improved the healing performance of cement mortar systems.