Development and performance of smart aggregates for self-healing of cement based materials

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Surface opening cracks are common defects in concrete structures. They allow penetration of water or other deleterious agents that result in loss of durability earlier than expected. Thus, repairing formed cracks and defects becomes essential and unavoidable. The conventional repair methods increase the life-cycle cost of concrete structures, have a significant environmental impact and need long and intensive labour. Over the past few decades, the notion that concrete can be designed with a sufficient healing capability and heal its cracks without any external aid has been an inspiring field of work for many research groups around the world. Given that the aggregates, including both fine and coarse, are the major constituent of any concrete mix, they had been expected to be widely utilised in developing the self- healing systems: however, this potential has not been extensively researched. Thus, this research investigates the self-healing capability of cement-based composites through the development of smart aggregates, which would either partially or completely replace aggregates in conventional cement-based mixes.

Two distinct self-healing systems were developed. The first system is developing pellets containing magnesium oxide, an expansive agent, as a potential self-healing agent. Silica fume and bentonite minerals were used in some formulations of the developed prototype pellets as well. As pellets were partially replaced the natural sand in mortar mixes, they were characterised in comparison with sand for the particle size distribution, density, porosity, crushing strength and particle shape. Experimental results indicated that the different types of pellets showed higher porosity and lesser crushing strength compared to the sand used. The second system is the impregnation of potential self-healing agents into lightweight aggregates (LWA). Two types of LWA with different sizes and different porosities were examined. As potential self-healing agents, three silica based liquid precursors were impregnated into the LWA particles and distilled water was also impregnated for comparative purposes. The two systems were then encapsulated in polyvinyl alcohol (PVA) as a coating material in order to protect the healing agents from any unwanted early release or reaction. The coating material was evaluated for the apparent solubility in water and in alkaline solution, swelling property, water permeability, dynamic mechanical properties, and shell thickness on pellets. Although PVA coating exhibited a decrease in its mechanical

properties in water or in simulated concrete environment (pH= 12.5), they maintained integrity and stability in both environments. The thickness of coating on the surface of pellets ranged between 10µm and 50µm. Moreover, the coated pellets displayed an increase in their crushing strength values by ~ 15-105%.

When pellets were embedded in mortar mixes as a 10% replacement by weight of sand, they showed negligible influence on the characteristics of the fresh mortars. However, this replacement caused a reduction in compressive strength of mortar samples by ≤ 15%. Nonetheless, the contribution of pellets in the formation of healing products to seal cracks of 300µm width was confirmed macroscopically by microscope observations and crack depth measurements with ultrasonic waves. Moreover, the samples containing the developed pellets showed a considerable regain of flexural strength and stiffness after two rounds of water curing of the cracked samples. The measured reduction in both water capillary absorption and gas permeability of the healed sections in the samples containing the developed pellets demonstrated substantial recovery of water and gas tightness compared to the control samples. The microstructure analysis confirmed the contribution of healing agents present in the incorporated pellets towards the formation of the healing products.

The performance of impregnated LWA was also investigated in concrete samples; they completely replaced the coarse aggregates in lightweight concrete mixes. It was found that the samples containing the impregnated LWA showed lower compressive strength values compared to the control; the reduction varied between 15% and 25% at 28 days, however it was ≤ 15% at 90 days. Nevertheless, the impregnation of the LWA particles by silica minerals resulted in a substantial enhancement of both strength and stiffness recovery at two rounds of healing. The capillary water absorption was also significantly improved; some samples not only attained complete recovery of the water-tightness at the cracked sections but also improved it compared to the uncracked sections. The contribution of silica minerals, released from the aggregates, in proliferation of the healing products was evident in all samples containing the impregnated LWA with silica precursors.

Overall, the two developed systems showed promising results in improving the self-healing capability of the cement based-composites. However, further investigations on the healing mechanism, the influence on the mechanical properties and improving the coating material used to encapsulate pellets and the impregnated LWA still need to be implemented.