Thesis Title: Characterisation and Performance Evaluation of Reactive Magnesia-Based Pervious Concrete for Application in Green Infrastructure

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The use of pervious concrete as paving material and one of the municipal green infrastructure practices recommended by the U.S Environmental Protection Agency (EPA) is fast increasing due to its associated environmental benefits. This class of concrete differs from conventional concrete mainly in material proportions, in which the amounts of fine aggregates and water are tightly controlled. This provides a material with the porosity and infiltration rate of ≥15% and ≥1mm/s respectively, mainly used as permeable paving of sidewalks, driveways, parking lots and low traffic residential roads. The principal hydraulic binder in pervious concrete is Portland cement (PC), the production of which is one of the most energy-intensive processes, and is responsible for ~5 to 8% of annual global anthropogenic carbon dioxide (CO_2) emissions. Therefore, there has been tremendous pressure on the cement industry to reduce its emissions towards carbon reduction initiatives, of which utilising industrial by-products and wastes as partial PC replacement as well as development of new cement formulations with lower environmental impacts have been most noticed in the past several years.

One such alternative is the recently emerged reactive magnesia (MgO) cements with a range of environmental and durability benefits over PC including: lower manufacturing temperature, substantial CO_2 sequestration, less sensitive to impurities and capable of blending with large quantities of supplementary cementitious materials (SCMs), and completely recyclable when used as a sole binder. As a new class of concrete, there is a dearth of knowledge about the effect of SCMs, admixtures and curing conditions on the mechanical and physical properties of pervious concrete. The use of SCMs and the newly developed reactive magnesia cements are not commercially considered in pervious concrete and could potentially enhance its sustainability aspects. Therefore, there is a real opportunity to develop innovative and sustainable binders for applications in pervious concrete.

Accordingly, the first part of this research was to investigate the properties of a large number of conventional and novel binder compositions (PC-GGBS (PG), MgO-GGBS (MG) and MgO-PC-GGBS (M-PII-G)) in the context of pervious concrete applications. The results showed that the optimum MgO content of 15-30% could activated the GGBS

used, thereby providing the UCS of ~30MPa and ~45MPa at 28 and 90 days respectively, still lower than the UCS of PG mixes. In the mixes containing both MgO and PC, the independent hydration of the two was observed, thus producing brucite and portlandite in the mixes. This led to the unexpected higher setting time and expansion of these mixes even higher than those of MgO-alone and MG mixes. The results further showed that the presence of limestone cement would enhance the mechanical properties of MG mixes which depends to a significant extent on the MgO/PC ratio in the mixture. The findings of carbonation curing revealed that the carbonation process in MG mixes interfered with the alkali activation of the slag by the MgO which was further verified through the applied microstructural analyses, by indicating the absence of Ht peaks in the carbonated samples as well as less CSH formed. The main hydration products in MG systems were CSH and Ht-like phases, while the presence of nesquehonite was also detected in the carbonated MG mixes.

The findings of concrete study clearly highlighted the crucial effect of mix composition, water content, admixtures, and curing condition on the engineering characteristics of the studied pervious concrete mixes. The use of GGBS and PFA in PC-based mixes showed comparable strength results to the control PC-alone, all in the range of 20-25MPa at 28 days and serving the minimum 1mm/s permeability requirement for pervious concrete. The MgO-based mixes under ambient curing showed little carbonation and hence very low strength attained (~2-9MPa), while the corresponding mixes under elevated CO_2 curing revealed a significant increase in the UCS to ~28MPa at 28 days. The porosity and permeability of these mixes were within the acceptable range for pervious concrete applications. Except for 25% PFA replacement, the incorporation of SCMs in the carbonated MgO-based mixes showed an adverse effect on the UCS. The use of admixtures (HRWR/SP, AEA and SBR) resulted in a 10-20% increase in the UCS as well as workability enhancement while meeting drainage requirements of pervious concrete. Up to 100% CO_2 sequestration was found within the produced pervious concrete mixes which contained only MgO.

Furthermore, the capability of selected pervious concrete mixes in immobilising common heavy metals in urban runoff (Zn^{2+}, Pb^{2+}, Cu^{2+}, Ni^{2+}, Cd^{2+}) was considered. The samples were loaded by metals solutions (individually or in multi-element solutions). The results indicated that the removal efficiency (RE) of the studied mixes was depended to a significant extent on the solution pH, which in turn varied under different mix compositions and concentrations of the metals used. The results showed more than 90% of the metals were removed from the solution over the seven days batch sorption test, which were ~40-60% higher than the findings of column test. This confirms the influence of the contact time, flow rate and metals concentration as the main factors affecting the concrete efficiency in this regard. The mechanism of Pb^{2+} uptake was found mainly through diffusion in the concrete matrix, thereby indicating a marginal difference under the solution conditions and the pH used. The findings of sequential extraction test revealed precipitation and surface complexation as the main and preliminary removal mechanism in the studied mixes.

Overall, the work clearly demonstrated the significant potential of MgO cement to be successfully used for the production of pervious concrete for a wide range of applications that makes this material ultra-green regarding reducing environmental impacts of PC production, potential CO_2 sequestration as well as in-situ stormwater runoff treatment.